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CONTENTS OF VOLUME LII

Bulletin No.		Plates	Pages
233.	Additional Data on New Zealand Astero- cyclina (Foraminifera)		
	By W. Storrs Cole	1-2	1-18
234.	Stromatoporoidea of Missouri		
	By Paul K. Birkhead	3-16	19-110
235.	Late Tertiary Biostratigraphy (Planktonic Foraminifera) of Tropical Indo-Pacific Deep-Sea Cores		
	By Frances L. Parker	17-32	111-208
236.	Foraminiferal Biofacies Variation and the Miocene-Pliocene Boundary in Southern California		
	By James C. Ingle, Jr.	33-43	209-394

INDEX

No separate index is included for the volume. Each number is indexed separately. Contents of volume is listed in the beginning of the volume.

21-B

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No. 233

**ADDITIONAL DATA ON NEW ZEALAND
ASTEROCYCLINA (FORAMINIFERA)**

By

W. Storrs Cole
W. STORRS COLE

1967

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W. STORRS COLE
Cornell University

February 15, 1967

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CONTENTS

	Page
Abstract	5
Introduction	5
Localities	6
Discussion and description of species	6
<i>Asterocyclina hornibrooki</i> , n. sp.	6
<i>Asterocyclina speighti</i> (Chapman)	10
Literature cited	12
Plates	13

ADDITIONAL DATA ON NEW ZEALAND ASTEROCYCLINA (FORAMINIFERA)*

W. STORRS COLE
Cornell University
Ithaca, New York

ABSTRACT

Abundant specimens of the foraminiferal genus *Asterocyclina* from a new locality in the Totara Limestone (upper Eocene) of New Zealand are compared with similar specimens previously assigned questionably (Cole, 1962, pp. 350, 351) to *Asterocyclina matanzensis* Cole (1957 a, p. 350) and *A. praecipua* Cole (1957 b, p. 780). The specimens identified as *A. matanzensis* are the megalospheric form and those referred to *A. praecipua* are the microspheric form of a new species, designated *A. hornibrooki*.

Specimens from another new locality in New Zealand, identified as *Asterocyclina speighti* (Chapman), are discussed and illustrated.

INTRODUCTION

In 1962 Dr. N. de B. Hornibrook, senior micropaleontologist of the New Zealand Geological Survey, requested me to study several collections of *Asterocyclina* from the Eocene of New Zealand. Although it was possible to obtain a sufficient number of satisfactory thin sections to redescribe and illustrate (Cole, 1962) *Asterocyclina speighti* (Chapman) (1932, p. 485), adequate preparations of *Asterocyclina* from the Totara Limestone (upper Eocene) could not be made as only a few specimens were available (Cole, 1962, p. 350).

However, from the fragmentary data obtained the specimens from the Totara Limestone were referred questionably to two species, *A. matanzensis* Cole and *A. praecipua* Cole. *A. matanzensis* was described from the upper Eocene of Saipan Island (Cole, 1957a), and *A. praecipua* from cores from the Eniwetok Atoll drill holes (Cole, 1957 b).

Recently Hornibrook forwarded two additional collections (locs. 1,3), one (loc. 1) of which contained abundant specimens of *Asterocyclina speighti*, and the other (loc. 3) had numerous specimens which proved to be identical with specimens previously identified as *A. matanzensis* and *A. praecipua*. Hornibrook (letter dated July 7, 1966) wrote concerning locality 3 "The age is Runangan Stage (upper Eocene) in the range zone of *Globigerapsis index* and should be the same age as the previous specimens I sent you from the Totara Limestone at Fortification Hill about five miles away."

In the same letter he included the following statement concerning locality 1 "The Waihao Greensand contains Bortonian (middle Eocene) Foraminifera elsewhere in the area and is underlain by sands and thin coal

* The cost of the printed plates has been contributed by the Gurley Fund of the Geological Sciences Department of Cornell University.

measures which in turn rest on basement. Locally, thin conglomerate lenses with silt lenses containing larger Foraminifera and oysters underlie the Greensand. The age of the large forams is likely, therefore, to be middle Eocene or older (I suspect Lower Eocene)."

Many of the thin sections made from the specimens are illustrated both by transmitted and reflected light so that all the details will be presented clearly. The major difficulty in the preparation of the thin sections was encountered in obtaining satisfactory exposure of the embryonic and periembrionic chambers as these chambers generally disintegrated as the section was made.

The specimens which are illustrated will be deposited in the collection of the New Zealand Geological Survey.

LOCALITIES

- Loc. 1—South Branch Waihao River, right bank, one-half mile upstream from the bridge; grid reference S. 127-448090, map edition 1943; New Zealand Geological Survey collection S. 127-740; P. A. Maxwell, collector.*
- Loc. 2—Fortification Hill, Oamaru; Totara Limestone (references: Hornibrook, 1961, p. 169; Cole, 1962, p. 345).
- Loc. 3—Old quarry in prominent east-facing escarpment three-quarters of a mile east of Clarke's flour mill, Maheno, Oamaru; top of Totara Limestone; New Zealand Geological Survey collection S 136-1065.
- Loc. 4—Station S 259, Saipan, Mariana Islands; Densinyama Formation (Tertiary *b*), limestone-conglomerate facies (reference, Cole, 1957 *a*, pl. 4).

DISCUSSION AND DESCRIPTION OF SPECIES

- Asterocyclus hornibrooki*** Cole, n.sp. Pl. 1, figs. 1-12, 16; Pl. 2, figs. 1, 5, 6, 8, 10
1962. *Asterocyclus matanzensis* Cole, Bull. Amer. Paleont., vol. 44, No. 203, pp. 350, 351, pl. 68, fig. 8, not *Asterocyclus matanzensis* Cole, 1957 *a*.
1962. *Asterocyclus praecipua* Cole, Bull. Amer. Paleont., vol. 44, No. 203, p. 350, pl. 68, fig. 9, not *Asterocyclus praecipua* Cole, 1957 *b*.

Specimens of Fortification Hill (loc. 2) were described (Cole, 1962, p. 350, 351) as follows:

The test is small with diameters from 0.9 to 1.9 mm. There are 4 to 6 rays which are distinct [Pl. 1, fig. 1] in some specimens and indistinct [Pl. 1, fig. 2] in others. These rays are more prominent in the peripheral zone and

* B. W. Riddolls, M.Sc. candidate at the University of Canterbury, discovered this locality and has an article in press in the New Zealand Journal of Geology and Geophysics describing it in detail.

fade into the central area. Many specimens have a slightly projecting central papilla [Pl. 1, figs. 1,8] with a diameter of about 100 μ . Smaller, less distinct papillae occur on the other parts of the test. The thickness of the test at the center is from 0.5 to 0.6 mm.

The embryonic chambers are large, the initial chamber has diameters of 110 by 130 μ , and the second chamber has diameters of 30 by 170 μ . The distance across both chambers is about 160 μ . The embryonic chambers are surrounded by a single ring of periembrionic chambers [Pl. 2, figs. 6,8].

The equatorial chambers are small with radial diameters of about 30 μ and tangential diameters of about 20 μ .

The lateral chambers are arranged in regular tiers [Pl. 1, fig. 6] with about 8 chambers at the center on each side of the equatorial layer. The chambers have a length of 40 to 80 μ , a height of 10 μ , and the roofs and floors have a thickness of 10 μ . Some sections have a strong central pillar [Pl. 1, fig. 11] with a surface diameter of about 100 μ . Much smaller pillars occur irregularly on the rest of the vertical section.

The description of the specimens from Fortification Hill (loc. 2) is supplemented by the study of the more abundant material from locality 3.

The specimens (loc. 3) are in general larger (diameter from 2.1 to 3.2 mm) and thicker (0.77 to 0.93 mm), otherwise they have the same external appearance.

Measurements of two equatorial sections, one from locality 2 and the other from locality 3 follow:

Table 1.—Measurements of Equatorial Sections of *Asterocyclina hornibrooki*

Locality	2	3
Specimen	Pl. 2, fig. 6	Pl. 1, fig. 12
Diameter mm	1.45	2.1
Embryonic chambers:		
Initial chamber μ	110 x 130	150 x 175
Second chamber μ	40 x 175	50 x 180
Distance across		
both chambers μ	160	210
Thickness of		
outer wall μ	15	20
Equatorial chambers:		
Radial diameter μ	40	40-60
Tangential diameter μ	20-30	20-30

The initial embryonic chamber is nearly circular. The second embryonic chamber is reniform and only slightly embraces the initial chamber (Pl. 1, fig. 12). The periembrionic chambers form a complete ring around the embryonic chambers.

Measurements of vertical sections of two specimens from Fortification Hill, (loc. 2) and of five specimens from locality 3 are given in Table 2.

Although the lateral chambers are arranged more or less in regular tiers, there is some overlap from tier to tier (Pl. 2, fig. 5). The equatorial chambers, especially along a ray near the periphery, become double (Pl. 1, fig. 3, right side). Many specimens have a strong central pillar (Pl. 1,

figs. 5, 7), but others do not (Pl. 2, figs. 4, 9).

Type specimen.—Figure 1, Plate 1: New Zealand Geological Survey catalogue No. TF 1555/1.

Discussion.—The megalospheric specimens from Fortification Hill (loc. 2) questionably assigned (Cole, 1962, p. 351) to *Asterocyclina matanzensis* Cole (1957*a*, p. 350) represent a new species, designated *A. hornibrooki*, in honor of Dr. N. de B. Hornibrook for his excellent research on New Zealand micropaleontological problems.

Cole (1962, p. 351) wrote "These specimens most nearly resemble those described from Saipan Island under the name *Asterocyclina matanzensis* (Cole, 1957*a*, p. 350) and later found in the Eniwetok drill holes (Cole, 1957*b*, p. 777). Until more specimens can be studied, they are assigned to this species.

"However, there are differences between the types of *A. matanzensis* and the New Zealand specimens. The types have double the number of lateral chambers to a tier, and some of the measurements are at variance with those of the New Zealand specimens. But, the resemblance in shape and configuration of the New Zealand specimens is nearest that of specimens assigned to *A. matanzensis* than to any other species."

Two illustrations, one by transmitted light (Pl. 2, fig. 7), the other by reflected light (Pl. 1, fig. 17) of a vertical section of a topotype of *A. matanzensis*, are given for comparison with *A. hornibrooki*. The lateral chambers of *A. matanzensis* are aligned in extremely regular tiers, are numerous, and the chamber cavities are low, whereas those of *A. hornibrooki* tend to overlap, are less numerous, and the chamber cavities are more open.

Satisfactory preparations of the embryonic chambers of the types of *A. matanzensis* were not obtained as the embryonic apparatus had been destroyed by replacement. Later specimens were recovered from the Eniwetok drill holes (Cole, 1957*b*, pl. 249, all figures) which are without question *A. matanzensis*. In preparations made from these specimens the embryonic chambers were preserved.

The embryonic chambers of *A. hornibrooki* are larger, the second embryonic chamber is distinctly reniform, and the ring of periembrionic chambers is better developed. These differences can be observed by comparing figure 6, Plate 2 with figures 4, 10, 16, plate 249 (Cole, 1957*b*).

A. matanzensis and *A. hornibrooki* have a general resemblance to *Asterocyclina stellata* (d'Archiac) (Neumann, 1958, pl. 30, figs. 1-7) from

Bartonian and Lutetian of France. However, the arrangement and shape of the lateral chambers are different in all these species.

Specimens (Pl. 1, fig. 16) with a few, large, raised papillae (Cole, 1962, p. 350, pl. 68, fig. 9) are rare, and in every case upon sectioning prove to be microspheric. Although this kind of specimen previously was assigned questionably (Cole, 1962, p. 350) to *Asterocyclina praecipua* Cole (1957 b, p. 780), they represent the microspheric form of *A. hornibrooki*.

***Asterocyclina speighti* (Chapman)** Pl. 1, figs. 13-15; Pl. 2, figs. 2-4, 9-11
1962. *Asterocyclina speighti* (Chapman), Cole, Bull. Amer. Paleont., v. 44, No. 203, pp. 346-350, pl. 67, figs. 1-10; pl. 68, figs. 1-7 (references).

Topotypes (Cole, 1962) are slightly larger (average diameter 3.2 mm.) than the specimens from locality 1 (average diameter 2.7 mm.). Many of the topotypes are distinctly rayed (Cole, 1962, pl. 67, figs. 4, 5), whereas most of the specimens from locality 1 are either biconvex (Pl. 1, fig. 15) or umbonate with a rim (Pl. 1, fig. 14) similar to the topotype illustrated as figure 6, pl. 68 (Cole, 1962). Externally the majority of the specimens from locality 1 resemble *Discocyclina*, and only a few specimens from this locality could be assigned to *Asterocyclina* by external appearance.

The equatorial chambers, however, are arranged in a rayed pattern (Pl. 2, figs. 9, 11) similar to that of topotypes (pl. 67, figs. 9, 10; pl. 68, figs. 1-3, Cole, 1962), and the embryonic (Pl. 2, figs. 9, 11; text-fig. 1) and periembrionic chambers are identical with those of topotypes. The distinctive embryonic apparatus is one of the best specific characters of *A. speighti*.

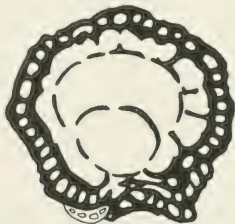


Figure 1.—Embryonic apparatus and the initial annulus of equatorial chambers, X 74, of the specimen illustrated as figure 11, Plate 2.

Several microspheric specimens were found at locality 1. A vertical section (Pl. 1, fig. 13) of one of these specimens is illustrated. These specimens have a diameter from 3.0 to 4.4 mm, but otherwise externally are similar to the nonrayed megalospheric specimens. The equatorial sections of the microspheric specimens have the equatorial chambers arranged in rays although in one individual the rayed arrangement of the equatorial chambers was not too pronounced.

Discussion.—Hornibrook (1958, p. 27 and Table 1) placed the beds in the vicinity of the Eyre River from which the types of *A. speighti* were obtained in the Mangaorapan Stage of the Dannevirke Series (lower Eocene). Later, he wrote (Cole, 1962, p. 349) "Finlay assigned the Eyre bed to the Mangaorapan stage, but the presence of a species of *Pseudobastigerina* rather suggests Heretaungan stage." This stage although stratigraphically above the Mangaorapan Stage is still assigned to the lower Eocene.

Specimens identified (Cole, 1962, p. 351) as *A. speighti* from the Chatham Islands occurred in limestones dated "as 'mid to upper Eocene' on the presence of *Globigerapsis index* (Finlay)." Another limestone from the Chatham Islands (Cole, 1962, p. 352) which contained specimens of *A. speighti* was dated as Paleocene by smaller Foraminifera.

The Waihao Greensand which overlies the lenses containing *A. speighti* at locality 1 is assigned to the Bortonian Stage (middle Eocene) (Hornibrook, letter dated July 7, 1966). However, the lenses with *Asterocyclina* seemingly do not contain smaller Foraminifera. Therefore, these lenses could be Bortonian or a stratigraphically older stage.

Data available suggest that *A. speighti* could range from the Mangaorapan Stage (lower Eocene) into the Bortonian. However, the association of *A. speighti* with "mid to upper Eocene" smaller Foraminifera at three localities in the Chatham Islands and the occurrence of Bortonian smaller Foraminifera above the lenses with *A. speighti* at locality 1 (South Branch Waihao River) suggest that *A. speighti* is a middle Eocene species.

As the specimens on which Chapman (1932) based *Asterocyclina speighti* were presumed to be lost (Cole, 1962, p. 342), the topotype specimen (pl. 67, fig. 5, Cole, 1962) (New Zealand Geological Survey catalogue No. TF 1461/1) was designated the neotype. Recently, Mr. D. R. Gregg, Keeper of Geology, Canterbury Museum, discovered and sent to Dr. Hornibrook two thin sections which are without question part of the material studied by Chapman.

Dr. Hornibrook (letter dated 17 October 1966) was able to recognize the following specimens illustrated by Chapman (1932, pls. 51, 52):

The thin section labelled "15, Tuff, Eyre R., *D. dispansa*, photo"—contained the specimens shown on plate 51, figure 1*a*, *b*, *c*; figure 2; and on plate 52, figure 6*a*, *b*. The thin section on which was written "015, Tuff, Eyre R., *Asterocyclina stellata*" had the specimens illustrated on plate 51, figure 4*a*, *b*, *c*.

The specimens illustrated by figures 3, 5, plate 51 could not be recognized.

Hornibrook wrote in this letter (17 October 1966) "It is obvious that Chapman called the vertical sections which missed the proloculus, *speighti*, and called the ones through the proloculus by other names", and he suggested ". . . that the specimen on slide 015 would be the best selection for lectotype because of the well preserved specimens next to it showing good proloculi." This recommendation is accepted.

The illustration (Chapman, 1932, pl. 51, fig. 4) shows three specimens designated in the explanation of plate 51 as (a) *Asterocyclina stellata*, (b) *Discocyclina speighti*, and (c) *D. dispansa*. All these specimens are *Asterocyclina speighti* (Chapman) of which the specimen labelled *b* is the lectotype by designation here as Chapman did not indicate in his publication or on the thin sections a type. This selection supercedes the designation of the neotype (Cole, 1962).

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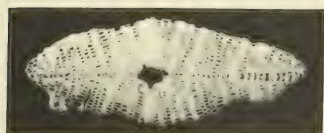
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PLATES

EXPLANATION OF PLATE 1

All figures, X 20, except 1,2,8, X 15; all figures by reflected light except 9,10.

Figure	Page
1,12,16. Asterocyclina hornibrooki Cole, n. sp.	6
1,2,8. External views to illustrate the variable development of the rays. 2,8. Specimens with a pronounced central papilla. 1. Holotype.	
3-7,9-11. Vertical sections of megalospheric specimens. 4,10. The same specimen, also illustrated as figure 5, Plate 2. 6. The same specimen as figure 1, Plate 2.	
12. Equatorial section of a megalospheric specimen.	
16. Vertical section of a microspheric specimen similar to the one previously identified (Cole, 1962, pl. 68, fig. 9) as <i>Asterocyclina praecipua</i> Cole.	
13-15. Asterocyclina speighti (Chapman)	10
13. Vertical section of a microspheric specimen.	
14,15. Vertical sections of megalospheric specimens. 14. The same specimen as figure 4, Plate 2. 15. The same specimen as figure 2, Plate 2. 14. With a rim; 15. Biconvex without a rim.	
17. Asterocyclina matanzensis Cole	9
Vertical section of a megalospheric specimen, topotype, introduced for comparison with <i>Asterocyclina hornibrooki</i> Cole, n. sp.; illustrated also as figure 7, Plate 2.	
1,2,6,8,11. Loc. 2—see text for locality descriptions.	
3-5,7,9,10,12,16. Loc. 3.	
13-15. Loc. 1.	
17. Loc. 4.	



3



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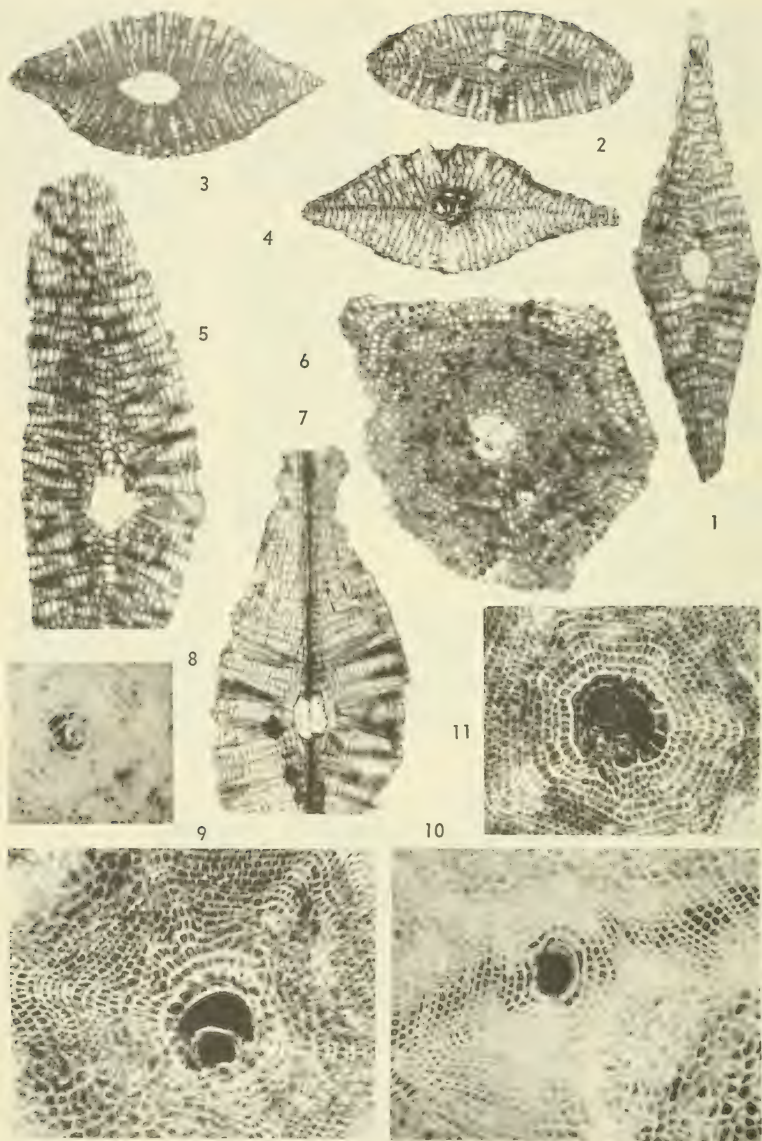
15



16



17



EXPLANATION OF PLATE 2

Figures 1, 5-10, X 40; 2-4, X 20; 1-6 by transmitted light; 7-11 by reflected light.

Figure	Page
1,5,6,8,10. <i>Asterocyclina hornibrooki</i> Cole, n. sp.	6
1,5. Vertical sections of megalospheric specimens. 1. The same specimen as figure 6, Plate 1. 5. The same specimen as figures 4,10, Plate 1.	
6,8,10. Equatorial sections of megalospheric specimens to illustrate the embryonic, periembryonic, and equatorial chambers.	
2-4,9,11. <i>Asterocyclina speighti</i> (Chapman)	10
2-4. Vertical sections of megalospheric specimens. 2. The same specimen as figure 15, Plate 1. 4. The same specimen as figure 14, Plate 1.	
9,11. Parts of equatorial sections of megalospheric specimens to illustrate the embryonic, periembryonic, and equatorial chambers. 11. Details of the embryonic apparatus shown as text-figure 1.	
7. <i>Asterocyclina matanzensis</i> Cole	9
Part of a vertical section of a topotype introduced for comparison with <i>Asterocyclina hornibrooki</i> Cole, n. sp.; also illustrated as figure 17, Plate 1.	
1,6,8. Loc. 2—see text for locality descriptions.	
2-4,9,11. Loc. 1.	
5,10. Loc. 3.	
7. Loc. 4.	

INDEX

Number 233

Note: Light face figures refer to the page number. Bold face figures refer to the plate numbers.

A		M	
Asterocyclina	1, 2 5-17	Maheno, New Zealand	6
B		Mangaorapan Stage	11
Bortonian Stage	11	Mariana Islands	6
D		matanzensis, Asterocyclina	1, 2 5, 6, 9
Dannevirke Series	11	N	
Densinyama Formation	6	New Zealand	
Discocyclina	10, 12	Geological Survey	5, 6
dispansa, Discocyclina	12	O	
E		Omaru, New Zealand	6
Eniwetok Atoll	5	P	
Eyre bed	11	praecipua, Asterocyclina	5, 6
Eyre River	11	Pseudohastigerina	11
F		R	
Fortification Hill, New Zealand	5-7	Riddolls, B. W.	6
G		S	
Globigerapsis	5, 11	Saipan, Mariana Islands	6
Gregg, D. R.	11	speighti, Asterocyclina	1, 2 5, 10-12
Gurley Fund	5	stellata, Asterocyclina	9, 12
H		T	
Hornibrook, Dr. N. de B.	5, 11, 12	Totara Limestone	5, 6
hornibrooki, Asterocyclina	1, 2 5-9	W	
I		Waihao Greensand	5
index, Globigerapsis	5, 11	Waihao River	6, 11

XXXV.	(Nos. 146-154). 386 pp., 31 pls.	16.00
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STROMATOPOROIDEA OF MISSOURI

By

PAUL K. BIRKHEAD

1967

Paleontological Research Institution
Ithaca, New York, 14850, U.S.A.

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CONTENTS

	<i>Page</i>
Abstract	23
Introduction	23
Acknowledgments	24
Stratigraphy of stromatoporoid-bearing strata	24
Ordovician	24
Silurian	25
Devonian	26
Stratigraphic position of the Missouri Silurian and Devonian stromatoporoids	27
Phylogeny of selected stromatoporoid genera as suggested by their develop- ment and succession	30
Register of collecting localities	30
Systematic descriptions	35
Order Stromatoporoidea	35
Family Clathrodictyidae	35
Genus <i>Clathrodictyon</i> Nicholson and Murie, 1878	36
Genus <i>Anostylostroma</i> Parks, 1936	40
Genus <i>Stictostroma</i> Parks, 1936	46
Genus <i>Stromatoporella</i> Nicholson, 1886	50
Family Actinostromatidae	60
Genus <i>Trupetostroma</i> Parks, 1936	60
Family Stromatoporidae	66
Genus <i>Ferestromatopora</i> Yavorsky, 1955	66
Genus <i>Stromatopora</i> Goldfuss, 1826	68
Genus <i>Taleastroma</i> Galloway, 1957	71
Genus <i>Syringostroma</i> Nicholson, 1875	73
Genus <i>Parallelopore</i> Bargatzky, 1881	75
Genus <i>Hermatostroma</i> Nicholson, 1886	78
Genus <i>Clathrocoilona</i> Yavorsky, 1931	79
Genus <i>Pseudoactinodictyon</i> Flugel, 1958	81
Family Idiostromatidae	83
Genus <i>Amphipora</i> Schulz, 1883	83
Genus <i>Stachyodes</i> Bargatzky, 1881	85
References	88
Plates	93
Index	109

FIGURES

	<i>Page</i>
1. Algal biostromes in the Joachim Formation of southeastern Missouri	Between 24,25
2. Biohermal development of algal mass in the Joachim Formation of southeastern Missouri	Between 24,25
3. Composite Silurian and Devonian sections of Missouri	Foldin 24,25
4. Exposure of the Cyrene Member of the Edgewood Formation at Clinton Springs, Missouri	Between 24,25
5. Exposure of the Cyrene Member of the Edgewood Formation, southeastern Missouri	Between 24,25
6. Exposure of the Sexton Creek Formation, southeastern Missouri	Between 26,27
7. Stromatoporoids associated with cup corals	Between 26,27
8. Correlation of the Devonian stromatoporoid-bearing strata of Missouri with other stromatoporoid-bearing, Devonian strata of North America and the Dinant Basin, Belgium	Between 28,29
9. Suggested relationships of selected stromatoporoid genera	30
10. Maculate tissue of <i>Clathrodictyon maculosum</i> n. sp.	Between 26,27
11. Index map of collecting localities	34

TABLES

	<i>Page</i>
1. Range of Callaway species of stromatoporoids as determined by ranges of similar species	Foldin 28,29
2. Range chart of Callaway stromatoporoids	29
3. Stratigraphic and geographic distribution of Missouri stromatoporoids	Foldin 34,35

STROMATOPOROIDEA OF MISSOURI

PAUL K. BIRKHEAD

Department of Chemistry and Geology
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ABSTRACT

Thirty-five species of stromatoporoids from the Silurian and Devonian rocks of Missouri are described. Twenty-eight of these species are new.

Ordovician outcrops, from which stromatoporoids have been reported, were searched. Stromatoporoids were not found in the Ordovician rocks, though algal stromatolites are common.

Silurian formations which contain stromatoporoids are the Edgewood of southeastern and northeastern Missouri, and the Sexton Creek of southeastern Missouri. All Silurian species belong to the genus *Clathrodictyon*. Evolutionary trends noted in *Clathrodictyon* are the development of true laminae and pillars, thicker pillar and laminar tissue, and definite astrorhizae.

Devonian stromatoporoid-bearing formations are the Grand Tower of southeastern Missouri and the Callaway and Snyder Creek of central Missouri. The abundance of stromatoporoid species found in the Callaway Formation made possible a comparison of the Callaway stromatoporoid fauna with stromatoporoid faunas of other regions. The lower part of the Callaway (Mineola facies) contains species which are most similar to species of the Jeffersonville Formation of Indiana (upper Lower Devonian or lower Middle Devonian). The middle part of the Callaway contains species similar to species of the Givetian of the Dinant Basin of Belgium and the Logansport Limestone (Givetian) of Indiana. The uppermost part of the Callaway contains species which compare with forms from the Upper Devonian (Frasnian) of the Dinant Basin and Alberta.

In a phylogeny developed from selected stromatoporoid genera, the Actinostromatidae and Stromatoporidae are derived independently through *Clathrodictyon*. *Actinodictyon* is derived directly from the line of *Clathrodictyon* with *Pseudoactinodictyon* stemming from *Actinodictyon*. *Idiostroma* and *Stachyodes* are related more closely to *Trupetostroma*, and *Amphipora* is placed closer to *Anostylostroma*.

INTRODUCTION

Stratigraphers and paleontologists familiar with the Paleozoic rocks of Missouri are aware of the abundance of stromatoporoids in the Silurian and Devonian strata of that state. The chief purpose of the following investigation is to systematically describe the Stromatoporoidea of Missouri.

Two species of stromatoporoids from the Devonian have been described (Keyes, 1894, p. 104; Branson, 1922, p. 56). One species from the Silurian (Savage, 1913, p. 364), and a species from the Ordovician (Larson, 1951, p. 2052), also have been reported in faunal lists. In the adjacent state of Iowa, eight species of stromatoporoids, all of Upper Devonian affinity, have been described by Parks (1936, pp. 57-77, 118-121).

A reconnaissance survey was made of the known stromatoporoid localities of the state and of other localities which were thought likely to contain stromatoporoid-bearing strata. Because of the areal extent of the reconnaissance, exhaustive collections were not

made at all sites. However, I believe a representative sampling of the stromatoporoids occurring in the region was obtained.

The stromatoporoid terminology and classification of Gallo-way and St. Jean (1957) is used throughout this study.

ACKNOWLEDGMENTS

The assistance given me, during the course of this study, by the following persons and institutions is greatly appreciated:

Professor A. G. Unklesbay, University of Missouri, for bringing to my attention the need for a systematic work on the Missouri stromatoporoids, and for the loan of stromatoporoid specimens from the University of Missouri Paleontological Collections.

Dr. Wallace B. Howe, Missouri Division of Geological Survey and Water Resources, furnished pertinent publications of the Missouri Survey and topographic maps of collecting areas.

Dr. Walter H. Wheeler, University of North Carolina, Chapel Hill, read the manuscript and offered constructive suggestions.

A grant was obtained from the Smith Fund of the University of North Carolina, Chapel Hill, to help defray transportation costs to field areas.

The Clemson University Faculty Basic Research Committee granted the funds needed to defray publication costs.

I am especially indebted to Dr. Joseph St. Jean, Jr., University of North Carolina, Chapel Hill, who read and criticized the manuscript and gave many hours to checking identifications of the stromatoporoids.

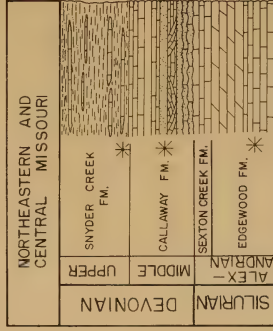
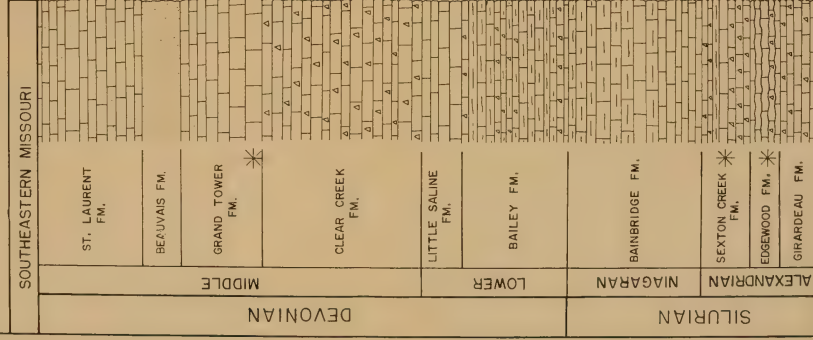
STRATIGRAPHY OF STROMATOPOROID-BEARING STRATA

ORDOVICIAN

Stromatoporoids were not found in a search of Ordovician localities, although they have been reported from Ordovician rocks of Missouri.

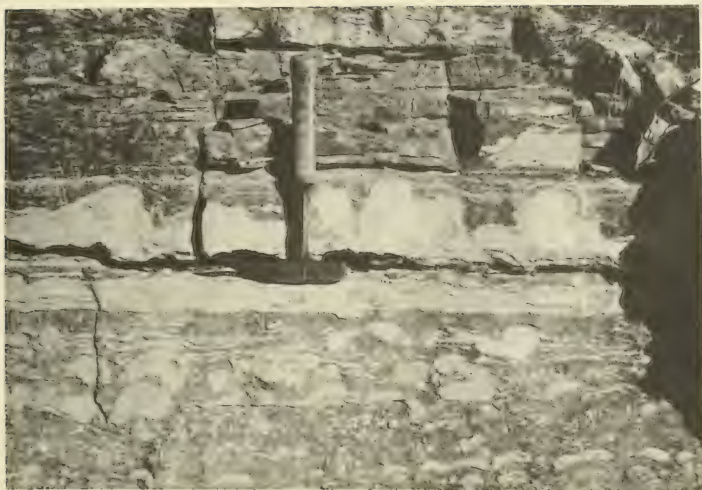
Larson (1951) gave group rank to the Ordovician Platin sequence of strata, dividing it into four formations: Bloomsdale, Beckett, Hager, and Macy. He reported *Cryptophragmus antiquatus* Raymond from the Beckett and Hager Formations, and *Cryptozoon* sp. (algae) from the Bloomsdale Formation. The subdivision

COMPOSITE SILURIAN AND DEVONIAN SECTIONS OF MISSOURI
(AFTER HOWE AND KOENIG, 1961)



* DENOTES OCCURRENCE
OF STROMATOPOROIDS

FIGURE 3



Text-fig. 1. Algal biostromes in the Joachim Fm. of SE Mo. The resemblance to stromatoporoid biostromes is evident. (Locality D).



Text-fig. 2. Biohermal development of algal mass in the Joachim Fm. of SE Mo. (Locality D).



Text-fig. 4. Exposure of the Cyrene Memb. of the Edgewood Fm. at Clinton Springs, Mo. (Locality 1).



Text-fig. 5. Exposure of the Cyrene Memb. of the Edgewood Fm. The rock contains irregular thin beds of chert and shale partings. SE Mo. (Locality F).

of the Platin into these formational units has not been adopted by the Missouri Geological Survey (Howe, Koenig, *et al.*, 1961).

Galloway (1957, p. 426) reported *Cryptophragmus* from the "Auburn Limestone". The term Auburn, first applied by Rowley (1908), is not used by the Missouri Geological Survey in connection with Ordovician stratigraphy, but is the name given to a Pennsylvanian formation of the Wabaunsee Group, Virgilian Series (Howe, Koenig, *et al.*, 1961). The "Auburn Chert", or "Auburn Limestone" is now considered to be the upper part of the Platin Limestone of Lincoln County, Missouri. Branson (1909) described the fauna of the "Auburn Chert" but did not mention *Cryptophragmus* or other stromatoporoids in his descriptions.

There is extensive stromatolite development at some horizons in the Jefferson City and Joachim Formations. They are formed in conjunction with algal growth, the algae occurring as biostromes (Text-fig. 1) or as biohermal masses up to three feet in basal diameter (Text-fig. 2) in the Joachim Formation. The extensive beds of stromatolites resemble stromatoporoid biostromes, but thin sections of structures prove them otherwise (Pl. 5, figs. 1-4).

SILURIAN

Stromatoporoids were found in the Sexton Creek Formation and in the Cyrene Member of the Edgewood Formation.

Savage (1913, p. 364) reported *Clathrodictyon vesiculosum* Nicholson and Murie from the upper "coral Layer" and Noix Oolite of the Cyrene Member (of northeastern Missouri) and the same species from the Sexton Creek Formation of southern Illinois and southeastern Missouri. He again reported and described *Clathrodictyon vesiculosum* (1917, p. 117) from the upper part of the Cyrene Member of the Edgewood Formation of southern Illinois and southeastern Missouri.

In northeastern Missouri the Cyrene Member is a light gray, crystalline limestone which contains an oolitic bed known as the Noix Oolite. At the locality where stromatoporoids were collected (Text-fig. 4) the Cyrene Member is 9.5 feet thick and unconformably rests on the Ordovician Maquoketa Formation. In southeastern Missouri the Cyrene Member is typically a gray, thin-bedded, argillaceous limestone in which yellowish-brown chert locally forms

thin beds, lenses, and nodules (Howe, Koenig, *et al.*, 1961, p. 34). Part of the stromatoporoid material, collected in southeastern Missouri, was taken from large boulders of the Cyrene Member which lie in a stream bed but which are in close proximity to an outcrop of that member in place (Text-fig. 5).

The Sexton Creek Formation consists of dark gray limestone with intercalated layers and nodules of chert. The chert layers stand out from the limestone beds on weathered surfaces, giving a characteristic rough appearance to the formation in outcrop (Text-fig. 6). At the collecting locality (L) the lower 10 feet of the formation can be observed. Relations between the Sexton Creek Formation and underlying and overlying formations are obscure. The upper part of the formation is soil covered or eroded away. The underlying Maquoketa Formation is of Ordovician age.

Gealy (1955), in his list of Sexton Creek fossils of the southeastern Missouri area, did not mention stromatoporoids but stated (p. 114) that "In Cape Girardeau and Jonesboro Quadrangles, Missouri, the Sexton Creek fauna is almost all corals with only a few other forms". Stromatoporoids were found in association with corals at Sexton Creek locality L (Text-fig. 6). Corals such as *Heliolites* (Pl. 4, figs. 5a, 5b), *Lyellia* (Pl. 4, figs. 4a, 4b), and other colonial corals can be confused with some stromatoporoid genera such as *Labechia*, especially in poorly preserved specimens. The cystose development of the coenenchymous tissue resembles the cyst plates of *Labechia*. Calyx walls appear to be pillars in vertical sections. Tangential sections are needed to differentiate stromatoporoids from some of the other coelenterate groups.

DEVONIAN

Devonian stromatoporoids were collected from the Grand Tower Formation of southeastern Missouri and from the Callaway and Snyder Creek Formations of central Missouri.

The best exposure of the Grand Tower Formation is at the Ozora Quarry in the Little Saline fault zone of Ste. Genevieve County (locality O) where the Grand Tower and Little Saline Formations are quarried for building stone. At locality O the Grand Tower Formation consists of light gray to white, fine to coarsely crystalline limestone which becomes arenaceous towards



Text-fig. 6. Exposure of the Sexton Creek Fm. illustrating cherty beds and rough weathered surface which is characteristic of the formation in outcrop. SE Mo. (Locality L).



Text-fig. 7. Stromatopora associated with cup corals; Cyrene Memb. of the Edgewood Fm. of NE Mo. The pencil lies between two stromatoporoid coenostea. (Locality I).



Text-fig. 10. (X 50). Vertical section of *Clathrodictyon maculosum*, n. sp. showing an area of thick cyst plates which are composed of maculate tissue.

the top as it grades into the overlying Beauvais Sandstone. The lowest part of the Grand Tower is dense, hard limestone, and contains numerous irregular chert nodules. The contact with the underlying Little Saline Formation is placed below the chert zone, but there is no sharp break between the two formations (Weller and St. Clair, 1928, pp. 139, 144). Above the chert zone corals are abundant. Stromatoporoids are found associated with the corals. They are not abundant, occurring as individual coenostea which are scattered among the more dominant colonial corals such as *Favosites* and *Hexagonaria*.

The lithology of the Callaway Formation varies considerably, both horizontally and vertically. The Ashland, Cooper, and Mineola facies were considered formations distinct from the Callaway until recently but are now included in the Callaway Formation (Unklesbay, 1952a, 1955; Howe, Koenig, *et al.*, 1961). Microcrystalline to crystalline limestone is the dominant lithology, with some arenaceous and argillaceous limestone interlayers. The Callaway is fossiliferous with stromatoporoids occurring at several horizons.

The Snyder Creek Formation is predominantly shale. The lower part is a gray-green shale containing thin layers of sandstone and limestone. Pyrite is present in the lower part of the formation in areas which may have been deeper basins during the time of Snyder Creek deposition. Limestone beds are frequent in some places near the contact with the underlying Callaway Formation. At some localities (K) the contact between these two formations appears conformable. There is a noticeable color change in the upper part of the Snyder Creek Formation to a yellowish, arenaceous shale which contains thin, brown limestone beds. The Snyder Creek is unconformably overlain by Mississippian strata. The age of the Snyder Creek is now considered Late Devonian because of the presence of diagnostic fossils in the formation such as *Manticoceras* (Unklesbay, 1952b). The genus *Stromatopora*, reported and described from the Snyder Creek by Branson (1922, p. 56, pl. 4, fig. 1; pl. 5, figs. 1-6), was identified as *Trupetostroma* by Parks (1936, p. 64).

STRATIGRAPHIC POSITION OF THE MISSOURI SILURIAN AND DEVONIAN STROMATOPORIDS

The corals found in the strata at localities F and L including *Halysites* sp., *Heliolites* sp., and *Lyellia* sp., identify the strata as the Cyrene Member of the Edgewood Formation and the Sexton Creek Formation (Savage, 1913; Gealy, 1955). Stromatoporoids were found associated with the corals. On the basis of simplicity of skeletal development of the Clathrodictyidae, the Cyrene Member of southeastern Missouri contains the most primitive Silurian stromatoporoids in Missouri, stromatoporoids from the Sexton Creek Formation seem to be intermediate in complexity, and those of the Cyrene Member of northeastern Missouri are the most complex (Pl. 6, figs. 1-4). Development of true laminae and pillars, thicker pillar and laminar tissue, and definite astrorhizae seems to be the trend in these Silurian stromatoporoids. Stromatoporoid development suggests that the Cyrene Member of northeastern Missouri should occur chronologically later than the Sexton Creek Formation of the southeastern part of the state. Environmental differences could explain the differences in complexity of development in the stromatoporoids taken from the Cyrene Member at the widely separated areas of the state. Stromatoporoids were found with cup corals (Text-fig. 7) in a light gray, oolitic, crystalline limestone (features indicating a high energy environment) in the northeast, whereas in the southeast they were taken from a gray, argillaceous limestone which included chert beds, nodules, and lenses (Text-fig. 5). The latter sedimentary features indicate quieter, deeper, somewhat turbid water.

The two stromatoporoid species collected from the lower part of the Grand Tower Formation resemble forms of Onondagan age from Ontario, Ohio, and Indiana.

Most of the Callaway species of stromatoporoids are new. Thus, comparisons with stromatoporoids of other regions are made on the basis of similar species (Table 1). There are two aspects to the Callaway stromatoporoid fauna, one of lower Eifelian and the other of Givetian and Frasnian. In a plot of ranges (Table 2) the maximum overlap occurs in the Givetian (Tioughniogan). Eleven species range into the Frasnian, of which two, *Trupetostroma vesiculosum* (Stearn) and *Parallelopora dartington-*

DEVONIAN			NORTH CENTRAL INDIANA (COOPER, 1942)	SOUTHERN INDIANA AND NORTHERN KENTUCKY	SOUTHEAST MISSOURI	CENTRAL MISSOURI	ALBERTA, CANADA (STEARNS, 1961 1962, 1963)	NORTHWEST TERRITORIES, (GALLAGHER, 1960)	DINANT BASIN, BELGIUM (LECOMPTE, 1952)
UPPER	FRASNIAN	SENEGAN				→ SNYDER CREEK →			F 3. (ASSISE DE MATAGNE) F 2. (ASSISE DE FRASNES) F 1. (ASSISE DE FROMELNENES)
	MIDDLE	ERIAN				→ CALLAWAY (INCLUDING UPPER PART OF COOPER FACIES)	BEAVERHILL LAKE WATERWAYS FLUME	POST- Stringocephalus burtoni BEDS	
LOWER	EIFELIAN	ULSTERIAN		JEFFERSONVILLE	GRAND TOWER	→ CALLAWAY (PART OF MINEOLA)		Stringocephalus burtoni BEDS	G i. (ASSISE DE GIVET)
								Rodostrophia arabica ZONE Rensselaeria laevis ZONE	Co 2. (ASSISE DE COUVIN) Co 1. (ASSISE DE BURE)

CORRELATION OF THE DEVONIAN STROMATOPOROID-BEARING STRATA OF MISSOURI WITH OTHER STROMATOPOROID-BEARING
DEVONIAN STRATA OF NORTH AMERICA AND THE DINANT BASIN, BELGIUM.

FIGURE 8

RANGE OF CALLAWAY SPECIES AS DETERMINED BY RANGES OF SIMILAR SPECIES

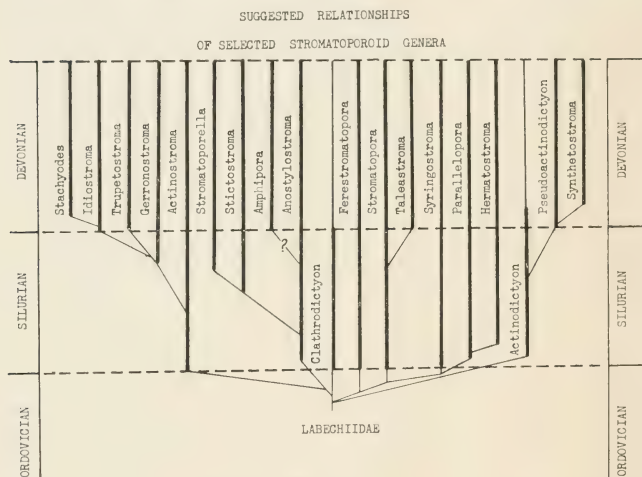
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TABLE 2
RANGE CHART OF CALLAWAY
STROMATOPOROIDS

	COBLENZIAN		EIFELIAN		GIVETIAN		FRASNIAN	
<i>Anostylostroma bifurcacolummare</i> n. sp.					—			
<i>Anostylostroma callawavensis</i> n. sp.					—		—	
<i>Stromatoporella congregabile</i> n. sp.			—		—			
<i>Stromatoporella turbata</i> n. sp.			—		—			
<i>Stromatoporella indubia</i> n. sp.					—			
<i>Trupetostroma ideale</i> n. sp.					—		—	
<i>Trupetostroma vesiculosum</i> (Stearn)							—	
<i>Trupetostroma adriani</i> n. sp.					—		—	
<i>Trupetostroma Kennisoni</i> n. sp.				—	—			
<i>Amphipora ramicosa</i> (Hillebrand)				—	—		—	
<i>Stachyodes crebrum</i> Stearn					—		—	
<i>Stachyodes spongiosum</i> Stearn					—		—	
<i>Ferestromatopora turbinata</i> n. sp.					—		—	
<i>Parallelopora dartingtonensis</i> (Carter)					—		—	
<i>Taleastroma pachytexta</i> (Lecompte)				—	—			
<i>Stromatopora congrua</i> n. sp.					—		—	
<i>Stromatopora indistincta</i> n. sp.				—	—			
<i>Syringostroma astrorhizoides</i> n. sp.				—	—			
<i>Hermatostroma insulata</i> n. sp.					—		—	
<i>Clathrocolonia subclathrata</i> Galloway and St. Jean					—		—	
<i>Pseudocleonicion mineolaensis</i> n. sp.				—	—			

ensis (Carter), are restricted to Frasnian beds. Eight species are similar to species from the Jeffersonville Formation of Indiana and Kentucky and Columbus Formation of Ohio (lower Eifelian ?). The horizon of the Callaway Formation which contains the lower Eifelian species is within the Mineola facies.

The two species of stromatoporoids found in the Snyder Creek Formation, *Stromatoporella foraminosa*, n. sp. and *Clathrocoilon subclathrata* Galloway and St. Jean, are of Middle Devonian affinity. It is my belief the specimens collected were derived from the underlying Callaway Formation. They were not found in place.



PHYLOGENY OF SELECTED STROMATOPOROID GENERA AS SUGGESTED BY THEIR DEVELOPMENT AND SUCCESSION

Some of the Missouri stromatoporoid species furnish additional information concerning the phylogeny of the stromatoporoids. The following observations have been considered in the construction of the phylogenetic chart. The chart is based on the one constructed by Galloway (1957, p. 396).

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF MISSOURI STROMATOPOROIDS

	LOCALITY													
	A	B	C	E	F	G	H	I	J	K	L	M	N	O
<i>Clathrodictyon incongruum</i> Birkhead, n. sp.	CALLAWAY													GRAND TOWER
<i>Clathrodictyon mamillatum</i> Birkhead, n. sp.	CALLAWAY											CALLAWAY		
<i>Clathrodictyon cyrenensis</i> Birkhead, n. sp.								X						
<i>Clathrodictyon maculosum</i> Birkhead, n. sp.								X						
<i>Anostylostroma bifurcolummare</i> Birkhead, n. sp.	X													
<i>Anostylostroma vermiculosum</i> Birkhead, n. sp.						X								
<i>Anostylostroma callawayensis</i> Birkhead, n. sp.	X													
<i>Anostylostroma spissa</i> Birkhead, n. sp.						X								
<i>Stictostroma ozarkense</i> Birkhead, n. sp.														X
<i>Stictostroma ordinarium</i> Birkhead, n. sp.	X													
<i>Stictostroma planulatum</i> Birkhead, n. sp.	X													
<i>Stromatoporella foraminosa</i> Birkhead, n. sp.										X				
<i>Stromatoporella congregabile</i> Birkhead, n. sp.	X					X								
<i>Stromatoporella turbata</i> Birkhead, n. sp.														
<i>Stromatoporella indubia</i> Birkhead, n. sp.	X													
<i>Stromatoporella ozoraensis</i> Birkhead, n. sp.						X								X
<i>Stromatoporella cryptomamillata</i> Birkhead, n. sp.														
<i>Trupestostroma ideale</i> Birkhead, n. sp.	X													X
<i>Trupestostroma vesiculosum</i> (Stearn)														
<i>Trupestostroma adriani</i> Birkhead, n. sp.		X					X							
<i>Trupestostroma kennisoni</i> Birkhead, n. sp.				X										
<i>Ferestromatopora turbinata</i> Birkhead, n. sp.									X					
<i>Stromatopora congrua</i> Birkhead, n. sp.	X													
<i>Stromatopora indistincta</i> Birkhead, n. sp.	X													
<i>Stromatopora granata</i> Birkhead, n. sp.						X								
<i>Parallelopora dartingtonensis</i> (Carter)							X							
<i>Parallelopora catenaria</i> Birkhead, n. sp.	X													
<i>Syringostroma astrohorizoides</i> Birkhead, n. sp.	X					X								
<i>Taleastroma pachytexta</i> (Lecompte)			X											
<i>Hermatostroma insulata</i> Birkhead, n. sp.												X		
<i>Clathrocolona subclathrata</i> Galloway and St. Jean						X				X		X		
<i>Pseudoactinodictyon mineolaensis</i> Birkhead, n. sp.						X								
<i>Amphipora ramosa</i> (Phillips)	X					X								
<i>Stachyodes crebrum</i> Stearn	X			X		X				X				
<i>Stachyodes spongiosum</i> Stearn	X			X		X				X				

TABLE 3

Clathrodictyon maculosum, n. sp. (Pl. 6, figs. 4a, 4b) found in the Cyrene Member of the Edgewood, has pillar and laminar tissue which is maculate in part (Text-fig. 10) but is basically finely fibrous and dusty appearing. The pillars and laminae of *C. maculosum* are thicker than those of other species of *Clathrodictyon*, and astrorhizae are developed to an advanced state. A species of *Stromatopora* would be produced from *C. maculosum* with complete development of maculate tissue and development of regular laminae.

Anostylostroma is here considered to be derived from *Clathrodictyon* by the development of a more coarsely fibrous skeletal tissue and regular pillars and laminae.

Stromatoporella ozoraensis, n. sp. (Pl. 3, figs. 7a, 7b; Pl. 9, figs. 4a, 4b) found in the Grand Tower Formation of early Middle Devonian age, has the distinct *Stromatoporella* characteristic of numerous, well-developed ring-pillars made of upturns of laminae (Galloway and St. Jean, 1957, p. 130). However, the skeletal tissue of *S. ozoraensis* is not the granular or tubulose type typical *Stromatoporella* (Pl. 3, fig. 5). The tissue is of the type found in *Stictostroma*, intermediate between that of *Anostylostroma* and the typical *Stromatoporella*.

Pseudoactinodictyon mineolaensis, n. sp. (Pl. 15, figs. 2a, 2b, 2c, 2d) has profuse development of dissepiments, similar in construction to the cyst plates of *Clathrodictyon*, with maculate laminae between dissepiments. Structures of this sort would seem to be requisite for forms between *Clathrodictyon* and *Stromatopora*.

The genus *Amphipora* may have affinity with *Anostylostroma*. Fibrous tissue and dark median area of the pillars are characteristics of both genera, although major structures are different.

There is no great difference in the skeletal tissue of *Trupetostroma* and *Idiostroma*. The two genera differ mainly in coenosteal form.

Stachyodes is closely related to *Idiostroma* in both form and tissue.

The tissue of the Callaway specimens of *Clathrocoilona subclathrata* Galloway and St. Jean (Pl. 16, figs. 1a, 1b) is morphologically similar, in some respects, to the tissue of *Stromatoporella* of the family Clathrodictyidae. Portions of the tissue have the

tubulose and granular-like structure of *Stromatoporella* even though maculate tissue is common. In parts of some coenostea where pillars are spool-shaped and superposed, where tissue is not maculate, and where the laminae are tripartite with clear median layer of tissue, the Missouri specimens of *C. subclathrata* resemble species of *Trupetostroma* of the Actinostromatidae.

Tissue types, in conjunction with geologic ranges, were primarily used as the basis for the construction of the phylogenetic chart. The chart differs from Galloway's phylogeny of the stromatoporoids (1957) in the following ways:

a. Genera of the Actinostromatidae and Stromatoporidae are derived independently through the line of *Clathrodictyon*.

b. *Actinodictyon* is derived directly from the line of *Clathrodictyon* with *Synthetostroma* and *Pseudoactinodictyon* stemming from *Actinodictyon*.

c. *Idiostroma* and *Stachyodes* are related more closely to *Trupetostroma*; *Amphipora* is placed closer to *Anostylostroma*.

The genera which were not found in Missouri but which are included in the chart were reviewed by study of slides from the Galloway and St. Jean collections now located at the University of North Carolina at Chapel Hill.

REGISTER OF COLLECTING LOCALITIES

- A. Callaway Formation; west side of road in steep valley wall of Stinson Creek, in south central part of section 1, T 46 N., R. 9 W.; about 2 miles northeast of Ham's Prairie, Callaway County, Missouri.
- B. Callaway Formation; at Adrian Brothers Quarry; NE $\frac{1}{4}$ NW $\frac{1}{4}$ section 24, T. 45 N., R. 12 W.; 0.2 mile north of U.S. Highway 63; Boone County, Missouri.
- C. Callaway Formation; on U.S. Highway 40; west side of Loutre River valley, north side of highway; near Callaway and Montgomery County line, Missouri.
- D. Joachim Formation; north side of Missouri Highway 74; 0.8 mile east of Pecan Grove School; 2.5 miles west of junction of Highway 74 and U.S. Highway 61; Cape Girardeau County, Missouri.
- E. Callaway Formation; Kennisson Quarry, east of Holt's Sum-

- mit, Missouri; NE $\frac{1}{4}$ section 30, T. 45 N., R. 10 W.; Callaway County, Missouri.
- F. Cyrene Member of Edgewood Formation; southeast Missouri; N $\frac{1}{2}$ NW $\frac{1}{4}$ section 12, T. 31 N., R. 13 E.; stream cut along the east branch of Cape La Croix Creek; Cape Girardeau County, Missouri.
- G. Callaway Formation; 3 miles south of Mineola, Missouri, along county road J, at a road cut near a road fork; NE $\frac{1}{4}$ NE $\frac{1}{4}$ section 15, T. 47 N., R. 6 W.; Montgomery County, Missouri.
- H. Callaway Formation; 3 miles northwest of Otterville, Missouri; center of section 29, T. 46 N., R. 19 W.; Cooper County, Missouri.
- I. Cyrene Member of Edgewood Formation; northeast Missouri; at Clinton Springs; NE $\frac{1}{4}$ NW $\frac{1}{4}$ section 20, T. 54 N., R. 1 W.; Pike County, Missouri.
- J. Callaway Formation; valley of Auxvasse Creek in the east $\frac{1}{2}$ of section 8, T. 48 N., R. 8 W.; Callaway County, Missouri.
- K. Snyder Creek Formation; mouth of Cow Creek; section 22, T. 47 N., R. 8 W.; Callaway County, Missouri.
- L. Sexton Creek Formation; N $\frac{1}{2}$ NW $\frac{1}{4}$ section 12, T. 31 N., R. 13 E.; stream cut along the east branch of Cape La Croix Creek; $\frac{1}{4}$ mile north of locality F; Cape Girardeau County, Missouri.
- M. Callaway Formation; about 2 $\frac{1}{2}$ miles along the only road that leads north from Williamsburg, Missouri, at a road cut; NW $\frac{1}{4}$ NW $\frac{1}{4}$ section 10, T. 48 N., R. 7 W.; Callaway County, Missouri.
- N. Callaway Formation; east of Ashland, Missouri on county road Y; SW $\frac{1}{4}$ SE $\frac{1}{4}$ section 17, T. 46 N., R. 11 W.; Boone County, Missouri.
- O. Grand Tower Formation; 1 mile west of Ozora, Missouri on Little Saline Creek; Ozora Marble Company Quarry; Ste. Genevieve County, Missouri.

Index Map Of Collecting Localities

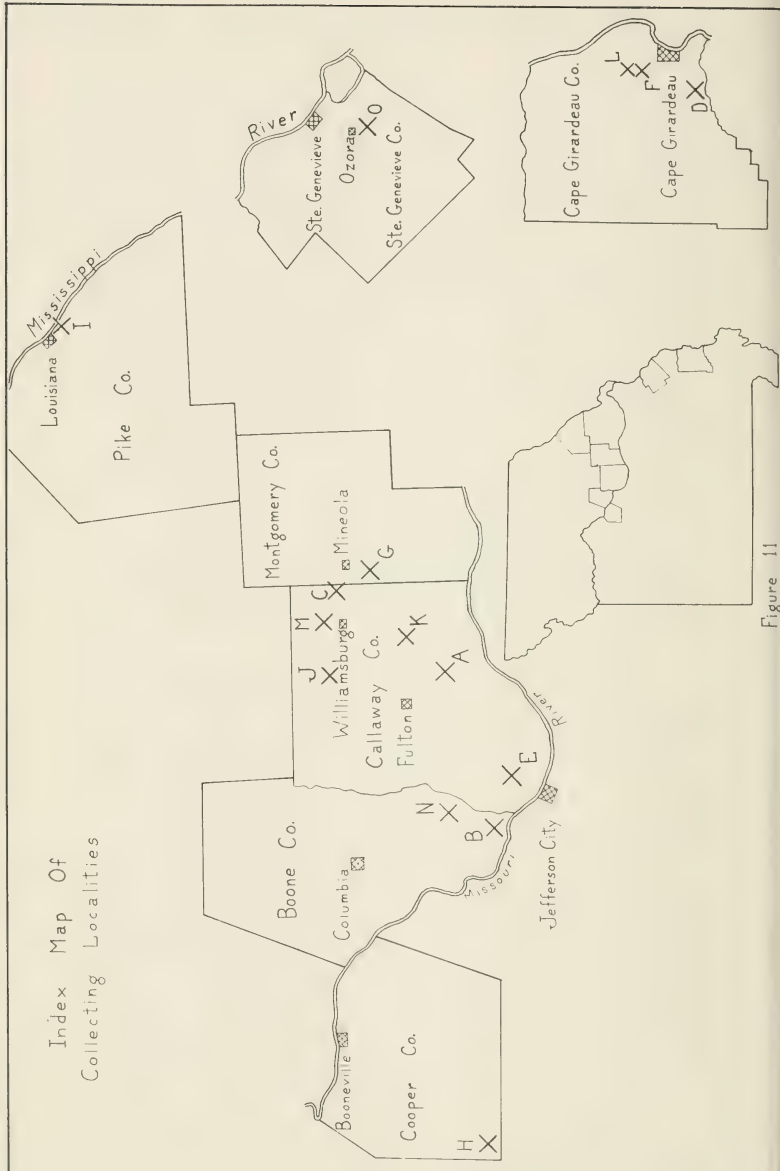


Figure 11

SYSTEMATIC DESCRIPTIONS

Phylum COELENTERATA

Class HYDROZOA

Order STROMATOPOROIDEA Nicholson and Murie, 1878

Section Stromatoporoidea Nicholson and Murie, 1878, Linn. Soc. London, Zool. Jour., vol. 14, p. 241.

Order Stromatoporoidea Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 73; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, p. A36; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F127; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 86; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 413.

Coenosteum originally calcareous and secreted as a skeleton by the animal; laminar, massive with varying shape, ramose, or dendroid, some with basal peritheca, usually latilaminar, may or may not have mamelons; coenosteum composed of outwardly convex, curved plates arranged in layers, or of thin or thick laminae, usually with vertical or radial, short or long pillars, with or without vertical, superposed galleries; skeletal tissue minutely vesicular, fibrous, maculate, tubulate, or compact (solid throughout, no microstructures except for finely crystalline calcite), without spicules and not composed of trabeculae; horizontal and vertical structures are discrete or amalgamated; astrorhizae are present or absent; some coenostea with symbiotic, tubular organisms.

Family CLATHRODICTYIDAE Kühn, 1939

Family Clathrodictyonidae, nov. fam., Kühn, 1938, Zentralbl. Miner., Abt. B, Geol., Palaeontology, p. 338.

Familia Clathrodictyonidae Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, Bd. 2A, p. A42.

Family Clathrodictyidae Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F128; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 90; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 432.

Coenosteum laminar to massive, composed of cysts side by side in concentric layers, or of laminae which are generally parallel, and short pillars; galleries higher than laminae are thick; foramina may occur between superposed galleries; pillars normally present, confined between two laminae, but may be incidentally superposed; tissue compact, fibrous, dusty appearing, tubulose or vacuolate, generally not maculate but one Missouri species partially so; astrorhizae may or may not be present.

Genus **CLATHRODICTYON** Nicholson and Murie, 1878

Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 77; *ibid*, 1889, vol. 42, p. 147, pl. 17, figs. 10, 11; Nicholson, 1887, Ann. Mag. Nat. Hist., ser. 5, vol. 19, p. 1, pl. 1, figs. 1-3; Twenhofel, 1927, Canada Dept. Mines, Geol. Sur., Mem. 154, No. 135, p. 107; Ripper, 1937, Roy. Soc. Victoria, Proc. new ser., vol. 50, p. 1; Kühn, 1939, in *Schindewolf*, Handbuch Paläozoologie, Bd. 2A, p. A42; Lecompte, 1951, (part), Inst. Roy. Sci. Nat. Belgique, Mém. 116, p. 129; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F128. Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issle-dovatel'skogo Geol. Inst., Minister. Geol. i Ochrany Nedr, nov. ser., vol. 8, p. 39; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 91; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 433, pl. 31, fig. 4; pl. 33, fig. 5.

Type species, *Clathrodictyon vesiculosum* Nicholson and Murie, 1878, Linn. Soc. London, Zool. Jour., vol. 14, p. 220, pl. 2, figs. 11-13 (Middle Silurian, Yellow Springs, Ohio).

Coenostea of the Missouri species of *Clathrodictyon* discoid to massive, hemispherical; mamelons absent but may have mamillae; skeleton composed of cyst plates placed side by side, forming galleries; arrangement of cyst plates sometimes produces a regular laminar effect, some have a chevron arrangement; plates thin or thick; galleries oval to elongate; downturned ends of cysts serve as pillars, some take on Y-shaped appearance; tissue fibrous, with dusty flecks, some tissue with vacuities; the more primitive forms composed of cyst plates not regularly arranged, producing laminar and pillar appearance; one Missouri species, *Clathrodictyon maculosum*, has maculate tissue.

Clathrodictyon incongruum Birkhead, n. sp. Pl. 3, fig 3; Pl. 6, figs. 1a, b

Coenosteum.—Hemispherical, or discoid masses, 1 to 7 cm high, up to 13 cm in diameter; surface smooth with gentle undulations; no astrorhizae, mamelons, or papillae observed on surface; vertical section with latilaminar appearance due to differential weathering of irregularly silicified specimens.

Vertical section.—Tissue dusty, finely fibrous; skeleton consists of cyst plates arranged end to end, forming irregular laminae, some joined in such fashion as to produce Y-shaped pillars; laminae average 0.06 mm in thickness, 14 to 16 in 2 mm, regularly linear in places, becoming irregular in other places in the same thin section; pillars of the same thickness and composition as laminae and continuous with them, not superposed; galleries sub-

oval to irregularly rectangular, averaging 0.30 mm in breadth but some reaching 1.5 mm; no pseudozooidal tubes, astrorhizae, or mamelon structures indicated in vertical section.

Tangential section.—Pillars round, 0.06 to 0.10 mm in diameter; most pillars appear to be connected by narrower processes which are traces in the plane of the thin section of the cyst plates making up the laminae and pillars, these traces giving an irregular network appearance to the section; galleries anastomose; astrorhizae may be indicated by vague, canal-like structures which seem to radiate from a central tube; gallery space represents 60% of the section.

Discussion.—The species is characterized by nearly regular, concentric laminae built of closely spaced transverse fibers. It is similar to *Clathrodictyon vesiculosum* Nicholson and Murie, but laminae of *C. incongruum* have an overall more regular appearance. The trivial name refers to the regularly linear to irregular laminae which occur throughout coenostea of this species.

Occurrence.—Coenostea of *Clathrodictyon incongruum* are found scattered individually through the Cyrene Member of the Edgewood Formation of the southeast Missouri area. All specimens collected have undergone some silicification. They occur in an irregular, thin bedded limestone. Each bed is separated from the next by a thin, green shale parting. Associations include *Halysites* sp. and another colonial coral with close affinity to *Lyonsia* sp.

Holotype.—North Carolina University Paleontological Collections, slides 310-9, 10. Cat. No. 3623; Paratypes, slides 310-7, 8, 11.

***Clathrodictyon mamillatum* Birkhead, n. sp.**

Pl. 6, figs. 2a, b

Coenosteum.—Hemispherical in form, most complete specimen 4.5 cm high and 8.2 cm in diameter; surface covered with small, low, closely spaced mamillae, but mamelons and astrorhizae absent; all specimens silicified in part, vertical surfaces contain resistant bands of silica which stand out on weathering; latilaminae obscured by silicification but prominent in vertical section.

Vertical section.—Tissue dusty, finely fibrous; laminae are rows of curved cyst plates which form oval-shaped galleries, laminae thin, 0.03 to 0.08 mm thick, averaging 0.05 mm, undulatory but not prominently zigzag, turn upward into mamillar columns; pillars

equal the laminae in thickness and are continuous with them; galleries vesicular to subrectangular, 0.06 to 0.33 mm broad, averaging 0.16 mm, 0.06 to 0.13 mm high, averaging 0.08 mm, most galleries only slightly broader than high; vertical sections of the species do not look the same when upside down or right side up, as is true for many species of *Clathrodictyon* (Galloway and St. Jean, 1957, p. 91), because of the upturns of laminae into the mamillar columns.

Tangential section.—Pillars round, 0.05 to 0.09 mm. in diameter, averaging 0.07 mm, some connected by thin processes which represent traces of curved, closely spaced, cyst plates (which are laminae and pillars); locations of mamillae marked by clusters of circular rings of tissue, usually with a central ring surrounded by other rings; astrorhizal canals absent.

Discussion.—*Clathrodictyon mamillatum* is characterized by the small mamillar columns and equidimensional galleries arranged between undulatory laminae. It is similar to *Clathrodictyon vesiculosum* Nicholson and Murie but has mamillae and does not have astrorhizae. The trivial name refers to the extensive development of mamillae in the species.

Occurrence.—Sexton Creek Formation; found scattered through limestone in southeast Missouri above the horizon of *Clathrodictyon incongruum*.

Holotype.—North Carolina University Paleontological Collections, slides 310-16, 17. Cat. No. 3624.

***Clathrodictyon cyrenensis* Birkhead, n. sp.**

Pl. 6, figs. 3a, b

Coenosteum.—Only fragments of coenosteum collected; occurs in hemispherical masses, but dimensions of a complete specimen not obtained; diameter of base of a coenosteum was 6 cm; no astrorhizae or mamelons observed on surface; latilaminae indefinite.

Vertical section.—Tissue dusty, finely fibrous; skeleton consists of vesicles of irregular shape, composed of cyst plates of thick tissue; pillars and laminae are continuous, of same thickness, averaging 0.10 mm thickness, laminae irregular, not continuous, form rough zigzag pattern in parts of vertical section; galleries average 0.13 mm in height and are only slightly broader; no mamelons, astrorhizal, or papillar structures present.

Tangential section.—Pillars round, average 0.07 mm in diameter, most connected by processes of thicker but less dense tissue (connecting processes not rodlike, as in *Atelodictyon*, but are simple cyst plate material), giving the irregular network appearance of other species of *Clathrodictyon* to the section; indications of astrorhizae are given by a few ringlike structures 0.12 mm in diameter from which radiate what appear to be short, thick, astrorhizal canals which are bound by cyst plate and pillar tissue; galleries vermicular to anastomosing; about 50% of the section is gallery space and 50% tissue.

Discussion.—Distinctive features are thick tissue of pillars and laminae, irregularity of laminae, absence of papillae and mamelons. The irregularity of cyst plates produces an anastomosing skeletal structure which can be seen in vertical section. *Clathrodictyon cyrenensis* is similar to *C. vesiculosum* Nicholson and Murie but has thicker laminae and pillars, and less regular laminae. It is similar to *C. confertum* Nicholson but has more widely spaced laminae and pillars. *C. cyrenensis* apparently is a form intermediate between *C. vesiculosum* and *C. maculosum* Birkhead, n. sp.

Occurrence.—Cyrene Member of Edgewood Formation of northeast Missouri; associated with *Clathrodictyon maculosum*, n. sp. and small cup corals; found in light gray, crystalline limestone which contains scattered oolites; named for occurrence in Cyrene Member of the Edgewood Formation.

Holotype.—North Carolina University Paleontological Collections, slides 310-14, 15. Cat. No. 3625.

***Clathrodictyon maculosum* Birkhead, n. sp.**

Pl. 6, figs. 4a, b

Coenosteum.—Hemispherical form, base slightly concave, height 4.7 cm, diameter 7.5 cm; surface rough, with pits and papillae, no mamelons; astrorhizae present, small, 2.0 mm in diameter and 4.0 mm between centers; latilaminae are light and dark bands, dark bands one lamina in thickness, marked by a row of galleries larger than average, 9 to 11 latilaminae in 1 cm.

Vertical section.—Tissue finely fibrous, dusty appearing, becoming maculate appearing in areas of minimal alteration; pillars and laminae thick, continuous with one another, average 0.10 mm in thickness, 12 to 15 laminae in 2 mm, laminae regular, arranged

in zigzag pattern due to connection of adjacent Y-shaped pillars which form the edges of the cyst plates; galleries ovaloid vesicles bound by thick cystose tissue, from 0.06 mm to 0.13 mm in height and breadth; astrorhizal columns present, astrorhizae superposed, astrorhizal tubes branching, from 0.26 to 0.30 mm in diameter.

Tangential section.—Pillars round, vermicular, some coalescing, 0.10 mm in diameter and 0.04 mm apart where not coalescing; galleries anastomosing; pillars not connected by radial processes; astrorhizae well developed, with central tube 0.20 to 0.40 in diameter and four or five short, radiating, bifurcating or nonbifurcating canals which average 0.20 mm in width, astrorhizae about 2.60 mm in overall diameter; about 70% of the tangential section is tissue with the remaining space galleries and astrorhizal tubes and canals.

Discussion.—*Clathrodictyon maculosum* Birkhead is characterized by thick zigzag laminae, partly maculate tissue, well-developed and superposed astrorhizae. It is similar to *C. fastigiatum* Nicholson in having the zigzag pattern of laminae, but the tissue of laminae and pillars of *C. maculosum* is thicker, and development of astrorhizae is more pronounced. *C. maculosum* is an advanced species of *Clathrodictyon*. The maculate tissue, to which the trivial name refers, is a significant step in the direction of the family Stromatoporidae.

Occurrence.—Cyrene Member of the Edgewood Formation of northeast Missouri; found in light gray, oolitic, crystalline limestone with *Clathrodictyon cyrenensis* and small cup coral.

Holotype.—North Carolina University Paleontological Collections, slides 310-12, 13. Cat. No. 3626.

Genus **ANOSTYLOSTROMA** Parks, 1936

Clathrodictyon (part) of authors, including forms with definite laminae and pillars; Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst., Minister. Geol. i Ochrany Nedr. nov. ser., vol. 8, pp. 40-58, pls. 19-23. Lecompte, 1951, "Groupe 2", Inst. Roy. Nat. Belgique, Mém. 116, p. 133. Lecompte, 1956, in Moore, Treatise Invert. Paleont., pt. F, p. F128, figs. 105-2, 3.

Stylodictyon Parks (not Nicholson and Murie, 1878), 1908, Univ. Toronto Studies, Geol. Ser., No. 5, p. 29, pl. 12, figs. 1-2; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, Bd. 2A, p. A43, fig. 60; Shimer and Shrock, 1944, Index Fossils of North America, p. 61, pl. 18, figs. 23, 24 (not Silurian, but Middle Devonian, Jeffersonville Limestone).

Type species, *Anostylostroma hamiltonense* Parks, 1936, Univ. Toronto Studies, Geol. Ser. No. 39, p. 44 (Middle Devonian, Traverse Group, Long Lake, Michigan).

Coenosteum flat to massive, with definite laminae and pillars; tissue fibrous, sometimes with vacuities, pillars of more compact, transversely fibrous tissue than laminae; pillars short, some Y-shaped, superposed in some species, not in others, round to vermicular-shaped in tangential section; galleries distinct, most of rectangular shape; dissepiments common in some species, absent in others; columns of uparched laminae may or may not be present. Missouri specimens characteristically have a dense, fibrous tissue.

Anostylostroma bifurcacolumnare Birkhead, n. sp. Pl. 7, figs. 2a, b, c

Coenosteum.—Occurs in globular masses; surface irregular with ragged, sharp ridges and depressions; height of an average size specimen is 5 cm, diameter 7.5 cm; mamelons numerous, vary considerably in diameter, height, and spacing; height of mamelons from 1 to 4 mm, diameter from 1 to 5 mm, spaced from 3 to 10 mm from center to center; no papillae, astrorhizae, or latilaminae apparent on surface, but latilaminae are distinct on a cut vertical surface.

Vertical section.—Tissue fibrous; laminae regular, undulate sharply upward into mamelon columns, are transversely fibrous, commonly split into two laminae, laminae 0.04 to 0.11 mm thick, averaging 0.07 mm, six to eight in 2 mm, thicker in mamelon columns; pillars short, mostly between one interlaminar space, some superposed, usually spool-shaped, rarely Y-shaped, transversely fibrous, 0.06 to 0.17 mm thick, averaging 0.13 mm, six to eight in 2 mm, pillars thicker, more numerous, and longer in mamelons; galleries oval to subrectangular, 0.13 to 0.41 mm high, averaging 0.28 mm and 0.13 to 0.70 mm wide, averaging 0.29 mm; cyst plates rare, present in some of the larger galleries, mostly near the mamelon columns, tend to be low oblique to laminae; no distinct mamelon tubes present; bifurcating mamelon columns diverge at approximately 20 degrees and remain normal to the surface of the coenosteum after branching.

Tangential section.—Pillars circular to vermicular, 0.07 to 0.18 mm in diameter, averaging 0.14 mm, 0.14 to 0.21 mm apart;

one or two annuli of laminae surround locations of mamelons; mamelons with three or four oval to circular structures 0.08 to 0.24 mm in inside diameter, averaging 0.14 mm; galleries anastomosing, vermicular in mamelons; about 60% of area of tangential section is gallery space; no astrorhizae.

Discussion.—Distinctive features of *Anostylostroma bifurcoluminare* are the long mamelon columns, some of which bifurcate (the character for which the species is named), the development of longer and thicker pillars in the mamelon columns, and the ragged appearance of the mamelons and ridges of the surface of the coenosteum. It is similar to *A. mediale* Galloway and St. Jean, but the laminae are not so thick, mamelon columns are better defined by more sharply inflected laminae, and the columns are thinner than those of *A. mediale*. *A. columnare* (Parks) has a much more delicate skeleton and has more mamelons per cm² than *A. bifurcoluminare*, and has a laminar coenosteum.

Occurrence.—Near the top of the Callaway Formation in a greenish, shaly limestone; found with many colonies of *Favosites* sp.; may be debris of a channel fill.

Holotype.—North Carolina University Paleontological Collections, slides 310-18; 312-02. Cat. No. 3627.

***Anostylostroma callawayensis* Birkhead, n. sp.**

Pl. 3, fig. 4; Pl. 7,
figs. 1a, b, c

Coenosteum.—Massive, incomplete specimen is 8 cm high and 15 cm in diameter; surface is gently undulating, whorls and contours of laminae can be seen on weathered surface; no mamelons or astrorhizae are apparent on the coenosteum; latilaminae composed of light and dark bands, the dark bands usually not more than one lamina thick and the light bands averaging 0.10 mm, six to eight latilaminae in 1 cm.

Vertical section.—Tissue fibrous; laminae regular, undulating, transversely fibrous and light in color, thickness varies from 0.014 to 0.08 mm, averaging 0.07 mm, eight to ten in 2 mm; pillars short but superposed, with closely spaced transverse fibers darker in color than the laminae, a few Y-shaped, pillars in mamelons thicker, six to eight pillars in 2 mm; most galleries rectangular, some oblong and some oval, from 0.08 to 0.28 mm high, averaging 0.25 mm

and 0.08 to 1.20 mm in breadth, averaging 0.35 mm; astrorhizal or mamelon tubes extend through eight or nine laminae; dissepiments occur in galleries and mamelon tubes and substitute for laminae in some places; latilaminae not distinctly visible in vertical section.

Tangential section.—Laminar tissue compact, pillar tissue fibrous, dark; pillars mostly round but some vermicular, 0.08 to 0.21 mm in diameter, averaging 0.10 mm, from 0.04 to 0.14 mm apart, averaging about 0.07 mm; tubes in mamelons oblong in shape, 0.14 to 0.28 in diameter; one or two annuli of laminae mark positions of low mamelons; astrorhizae at center of mamelons consist of one or two central tubes with short, branching canals; galleries connected, anastomosing; thin section area divided about equally between tissue and gallery space.

Discussion.—Both pillars and laminae are transversely fibrous although laminar tissue has less well-defined fibrous tissue than the pillars. Pillar tissue is darker than that of the laminae. Y-shaped pillars are not common. *Anostylostroma callawayensis* resembles *A. dupontense* Galloway and St. Jean, but galleries are broader and not so high as in that species. Pillars are thicker and have more upward spread in *A. dupontense* which gives rise to pendant pillars in vertical section, a feature absent in *A. callawayensis*. *A. callawayensis* is also similar to *A. anacolumna* Tyler but differs in having astrorhizae, some of which are superposed in columns.

A. callawayensis is similar to some species of *Trupetostroma*, but the fibrous tissue of pillars and laminae and linear to vermicular appearing pillars in tangential section are distinguishing characteristics of the genus *Anostylostroma*. *A. callawayensis* also lacks the vacuolate tissue and microlaminar structure of *Trupetostroma*.

Occurrence.—Abundant in the upper part of the Callaway Formation to which the trivial name refers. A small cup coral is associated with *Anostylostroma callawayensis* and grows upright in one specimen collected. Some of the small corals are completely enveloped. One coenosteum has a large solution cavity which was filled with a matrix of white limestone and contains fragments of *Favosites* sp., *Stachyodes spongiosum* Stearn, *Anostylostroma callawayensis*, and small fragments of shells of other organisms, mostly brachiopods.

Holotype.—North Carolina University Paleontological Collec-

tions, slides 310-19, 20. Cat. No. 3629; in part, Univ. of Mo. Cat. No. 14717.

Anostylostroma spissa Birkhead, n. sp.

Pl. 8, figs. 1a, b, c, d

Coenosteum.—*Coenosteum* built up of undulating bands of latilaminae which vary in thickness; height of specimens varies from 1 to 20 mm, an incomplete specimen is 12 cm in diameter; surface smooth except where weathering has produced concentric rings of laminae; no mamelons present; no papillae but surface is pitted where weathered, the pits being depressions between pillars (as seen with hand lens); astrorhizae not apparent on surface.

Vertical section.—Tissue badly altered, apparently fibrous and dense; laminae regular, composed of lighter, less compact tissue than the pillar tissue, appear as light lines running through dense, gallery-filling tissue, laminae undulate gently into low domelike mamelons, laminae from 0.03 to 0.10 mm thick, averaging 0.06 mm, 12 to 16 laminae in 2 mm; pillars short, thick, of dark, transversely fibrous tissue, most occur between two laminae, not superposed, 0.04 to 0.17 mm thick, averaging 0.07 mm, 8 to 12 in 2 mm; galleries oval to subrectangular, from 0.07 to 0.14 mm high, breadth from 0.08 to 0.28 mm, averaging 0.17 mm, most gallery space filled with dark, tissue-like material; some astrorhizal tubes present, round in cross section, 0.04 to 0.14 mm in diameter, averaging 0.10 mm, not filled with dark, tissue-like material; no dissepiments present; dark tissue-like material occupies most of the space of the section.

Tangential section.—Tissue dense, probably fibrous but badly altered; gallery space filled with light-colored, tissue-like material, tissue comprises 95% of the section if filling material is considered; pillars vermicular, round, some coalescing, composed of dark, fibrous tissue, about 0.10 mm apart if not coalescent, diameter 0.03 to 0.14 mm, averaging 0.06 mm; galleries anastomose around pillars; astrorhizal canals present, slender, forking, have one or two central tubes of about 0.08 mm diameter, horizontal canals 0.06 to 0.14 mm in diameter.

Discussion.—*Anostylostroma spissa* is characterized by the large amount of tissue, which obliterates most of the gallery spaces and

obscures much of the structure (the characteristic to which the trivial name refers). Usually the only areas void of tissue are the astrorhizal canals. The filling material may be inorganically precipitated. However, the usual calcite filling of gallery spaces in stromatoporoids with well-defined galleries is clear and structureless, whereas the thickening material in the skeleton of *A. spissa* is fibrous or trabecular-like and seems to be organically produced. Another characteristic is the narrowly spaced laminae and pillars, accounting for small galleries. The dark, fibrous, vermicular pillars in *A. spissa* are characteristic of *Anostylostroma* and serve to distinguish it from members of the Stromatoporidae, with which it may be confused because of the thick coenostial structures. A broken, fresh surface of a coenosteum of this species has the appearance of dense, lithographic limestone. Protruding from the thicker parts of the coenosteum are narrower, curving, laminar portions, from which an occasional mamelon about 2 mm high and 2 mm in diameter has developed.

Anostylostroma spissa is similar to *A. vermiculosum* Birkhead, n. sp. but has thinner laminae, shorter pillars, laminae are more closely spaced than in *A. vermiculosum*, and there is a greater development of thickening tissue in *A. spissa*.

Occurrence.—Callaway Formation; enclosing limestone matrix is light gray in color and contains small fragments of shell material and limonite altered from pyrite. Cavities within the coenostea have been filled with large crystals of calcite. *A. spissa* is associated with *Amphipora ramosa* (Phillips).

Holotype.—North Carolina University Paleontological Collections, slides 310-21, 23, 25, 26. Cat. No. 3630.

***Anostylostroma vermiculosum* Birkhead, n. sp.**

Pl. 7, figs. 3a, b

Coenosteum.—Entire coenosteum not found; massive, forms layers in rocks; no astrorhizae, mamelons, or latilaminae observed on weathered surfaces, but laminae stand out; weathered tangential surface pitted due to anastomosing pillars projecting above surface; lighter and dark, narrow bands are seen on polished vertical section but are not continuous, light bands are areas where laminar and pillar tissue is more dense and gallery space is absent.

Vertical section.—Laminar tissue compact, light in color; pillar

tissue transversely fibrous, black in color; laminae irregular, from 0.05 to 0.16 mm thick. 11 to 13 in 2 mm, overlap one another in places; pillars short and thick, spool-shaped, a few superposed, none Y-shaped, average 0.09 mm in thickness, seven in 2 mm; galleries oval to rectangular, 0.10 to 0.46 mm broad, averaging 0.27 mm and 0.06 to 0.16 mm high; no mamelons or astrorhizae indicated in vertical section; dissepiments rare.

Tangential section.—Laminar tissue occurs as light bands crossing the section, is compact; pillars darker than laminae, transversely fibrous, round, elongate, vermicular, 0.10 mm thick and about 0.10 mm apart; galleries anastomose around pillars; some pillars connected by thin dissepiments; no astrorhizal structures present; tissue and gallery space evenly divided.

Discussion.—*Anostylostroma vermiculosum* is characterized by having compact laminar tissue and dark transversely fibrous pillar tissue, irregular spacing of laminae, and vermicular-shaped pillars. This species is similar to *A. callawayensis*, but laminar spacing is less regular, pillars are more vermicular in shape and spaced closer together, and astrorhizae are absent. It resembles *Stictostroma ordinarium* Birkhead, n. sp. but has transversely fibrous rather than tubulose tissue, laminae are not as regular, and pillars are vermicular rather than round in tangential section.

Occurrence.—Common in the Callaway Formation, locality G.

Holotype.—North Carolina University Paleontological Collections, slides 310-29, 30. Cat. No. 3632.

Genus **STICTOSTROMA** Parks, 1936

Stromatopora mamillata Nicholson, 1873, Ann. Mag. Nat. Hist., ser. 4, vol. 12, p. 94, pl. 4, fig. 4 (Middle Devonian, Port Colborne, Ontario); Nicholson, 1874, Rept. Paleontology Prov. Ontario, p. 17, pl. 1, fig. 4; Nicholson and Murie, 1878, Linn. Soc. London, Zool., Jour., vol. 14, pl. 1, fig. 10.

Stictostroma Parks, 1936, Univ. Toronto Studies, Geol. Ser., No. 39, p. 78, pl. 14, figs. 3-6 (Onondaga Formation, Ashton's Quarry, Gorrie, Ontario); Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 435, pl. 31, fig. 6; pl. 33, fig. 9.

Type species, *Stictostroma mamilliferum* Galloway and St. Jean, 1957, new name, Bull. Amer. Paleont., vol. 37, No. 162, p. 124, pl. 6, fig. 4 (Middle Devonian, Port Colborne, Ontario).

Coenosteum in thin, irregular crusts to massive; tissue fibrous with transverse tubules or cellules in laminae and pillars, pillar

tissue sometimes darker than laminar tissue; pillars short, confined to one interlaminar space, may have a few ring-pillars, pillars and laminae irregular in most of the Missouri species; surface of coenosteum smooth to mamillate; astrorhizae present in some species, but small; peritheca present, especially in crusty type coenostea.

***Stictostroma ozarkense* Birkhead, n. sp.**

Pl. 8, figs. 2a, b

Coenosteum.—Coenosteum small, lens-shaped or encrustations to 5 mm in thickness, convex at top and bottom, 1.8 cm high at center, 6 cm in diameter; surface has low, indistinct mamelons and ridges about 1 mm high and 4 to 5 mm apart; surface of the collected specimen has been water worn; contours of laminae are etched on surface in whorls; astrorhizae cannot be distinguished on the surface; latilaminae absent.

Vertical section.—Tissue finely fibrous in pillars; laminae 0.03 to 0.12 mm thick, averaging 0.07 mm, 10 to 12 in 2 mm, some tripartite laminae with upper and lower layers of finely fibrous tissue and median cellular or tubular layer, laminae turn up gently into low mamelons; pillars short, spool-shaped, with vacuities in parts abutting the laminae, a few Y-shaped, seldom superposed, averaging 0.09 mm in thickness, eight to ten in 2 mm; galleries oval to rectangular, 0.07 to 0.53 mm in breadth, averaging 0.20 mm, 0.06 to 0.20 mm in height, averaging 0.16 mm, some galleries connected with foramina; dissepiments rare.

Tangential section.—Tissue fibrous, with some vacuities present; pillars round, vermicular in mamelons, rarely vermicular or coalescent in other areas, 0.10 mm in diameter, about 0.06 mm apart; galleries anastomose around pillars; mamelons surrounded by one to three annuli of laminae, mamelons with central tube 0.23 mm in diameter; pillars spaced farther apart near mamelon tubes, giving appearance of short, thick, astrorhizal canals radiating from a central tube; astrorhizal canals average 0.20 mm diameter; no regular mamelon columns present; tissue and galleries each occupy about 50% of the section.

Discussion.—Distinctive features of *Stictostroma ozarkense* are the light median, cellular or tubulose layer of tissue in the laminae, low mamelons with contours of laminae in concentric rings showing distinctly in tangential section and on weathered surface. This

species is similar to *Stictostroma jeffersonvillense* Galloway and St. Jean, but laminae are thinner and more closely spaced, and mamelons are not so well developed as in *S. jeffersonvillense*. It also resembles *Anostylostroma laxum* (Nicholson), but mamelons are not so large, laminae consist of more than one layer of tissue, tissue is more cellular or tubular, and there are no tabulate axial mamelon tubes present as in *A. laxum*.

Occurrence.—Occasional coenostea found in white, crystalline Grand Tower Limestone at locality O. A freshly broken coenosteum has the appearance of gray, lithographic limestone.

Holotype.—North Carolina University Paleontological Collections, slide 312-01. Cat. No. 3631; in part Univ. of Mo. Cat. No. 14716.

***Stictostroma ordinarium* Birkhead, n. sp.**

Pl. 8, figs. 3a, b

Coenosteum.—Massive, incomplete specimen 8 cm high, 12 cm in diameter; surface highly irregular when weathered, with knobby protuberances, some 1.5 cm in diameter; no mamelons, papillae, or astrorhizae observed on surface; dark and light bands of laminae visible, from 1 to 3 mm thick, not continuous, six to eight in 1 cm.

Vertical section.—Tissue fibrous in pillars, transverse tubules in pillars and laminae; laminae vary in thickness, 0.03 to 0.13 mm, laminar tissue lighter in color than pillar tissue, eight to ten laminae in 2 mm; pillars short, composed of dark, fibrous tissue with transverse tubules, a few superposed but usually confined to one interlaminar space, from 0.06 to 0.17 mm thick, averaging 0.13 mm; astrorhizal tubes occur sporadically, 0.10 mm in diameter with short, branching canals; laminae and pillars crowded closer together in some areas of the section, eliminating gallery spaces and increasing density of tissue; laminae gently undulating, occasionally turning upward into mamelon columns; dissepiments rare.

Tangential section.—Pillars round, elongate, a few ring-pillars near laminar tissue bands, regular pillars from 0.10 to 0.20 mm in diameter, averaging 0.14 mm; ring-pillars about 0.40 mm in outside diameter; pillars have dark tissue in center; galleries anastomose around the pillars, same width as pillars; astrorhizae about 1.3 mm in overall diameter with central tube 0.10 mm in diameter and

short, irregular, radiating canals which do not branch, segments of astrorhizal canals about 0.10 mm in diameter also present in tangential section; tissue to gallery space is about 45% to 55%.

Discussion.—Distinctive features of *Stictostroma ordinarium* are the irregular spacing of pillars and laminae, a scattering of ring-pillars, and small, sporadic, superposed astrorhizae in small, widely spaced mamelon columns. *S. ordinarium* is similar to *S. jeffersonvillense* Galloway and St. Jean, but laminae are more closely spaced, mamelons and mamelon tubes are not so well developed, and dissepiments are fewer than in *S. jeffersonvillense*. *S. ordinarium* was not placed in the genus *Anostylostroma* on the basis of the presence of the few ring-pillars and tubular tissue. The species resembles *Anostylostroma callawayensis* Birkhead, n. sp., but laminae are more closely spaced, pillars are shorter and not so extensively superposed, and tissue is not so finely fibrous. If ring-pillars were more frequent and the tissue more coarsely tubulose, *S. ordinarium* would be placed in the genus *Stromatoporella*. The trivial name refers to the composite features which places the species in *Stictostroma*.

Occurrence.—Common in the Callaway Formation at locality A; is massively developed just above a bed of *Stachyodes spongiosum* Stearn and *Amphipora ramosa* (Phillips).

Holotype.—North Carolina University Paleontological Collections, slides 310-32, 33. Cat. No. 3633.

***Stictostroma planulatum* Birkhead, n. sp.**

Pl. 9, figs. 1a, b

Coenosteum.—Thin, platy, thickens and thins irregularly, height variable from 1 to 8 mm in a single coenosteum, incomplete specimen is 22 cm in diameter; surface undulatory and strongly mamillate; mamelons 2 to 4 mm in diameter at their base and taper to the top, 2 to 3 mm high, 5 to 8 mm from center to center, three to five in one sq. cm; no papillae, astrorhizae, or latilaminae; peritheca well developed, wrinkled.

Vertical section.—Tissue fibrous with tubules; pillars and laminae irregular; pillars with a median dark, fibrous line of tissue; pillars and laminae of equal thickness where they can be distinguished, 0.10 to 0.20 mm thick, averaging 0.13 mm; galleries more frequent beneath mamelons, oval to irregular in shape, 0.06 to

0.20 mm in diameter; no vertical mamelon or astrorhizal tubes; laminae swing sharply upward into mamelons.

Tangential section.—Ratio of tissue to gallery space difficult to determine due to extensive infiltration of skeleton by calcium carbonate; galleries cannot be distinguished except in areas of mamelons, oval to somewhat elongate in shape, average 0.10 mm in diameter; pillars round, elongate, some coalesce to make complete rings around gallery space, median dark line in pillar tissue; astrorhizae absent.

Discussion.—Distinctive features of *Stictostroma planulatum* are the flat, platelike coenosteum (to which the trivial name refers) with conspicuous mamelons and dark, median line of the pillars. The dense tissue development of pillars and laminae and flat, mamillate coenosteum resembles that of *S. kayi* (Parks) and *S. elevatum* (Parks), but those two species have a more tubulose tissue and do not have the dark median area in the pillars.

Occurrence.—Found in abundance in an impure limestone of the Callaway Formation at locality A. The limestone is silty, shaly, and contains pyrite. Large horn corals were found lying in random orientation on top of the *S. planulatum*-bearing bed. The associated lithology suggests that these flat stromatoporoids were able to exist in turbid, limy water.

Holotype.—North Carolina University Paleontological Collections, slides 310-35, 36. Cat. No. 3634, paratypes, slides 310-34, 37; holotype in part, Univ. of Mo. Cat. No. 14726.

Genus **STROMATOPORELLA** Nicholson, 1886

Stromatoporella Nicholson, 1886, Palaeontological Soc., vol. 39, p. 92, pl. 1, figs. 4, 5, 15; pl. 4, fig. 6; pl. 7, figs. 5, 6; Nicholson, 1891, vol. 44, p. 202, pl. 26, fig. 1 (*S. granulata* restricted to the form from the Hamilton Formation of Arkona, Ontario); Parks, 1907, Univ. Toronto Studies, Geol. Ser., No. 4, p. 29; Parks, 1936, No. 39, p. 90, pl. 16, figs. 1-7; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, Bd. 2A, p. A45; Yavorsky, 1943, Compte Rendu (Doklady) Acad. Sci. U.S.S.R., vol. 39, No. 9, p. 369; Yavorsky, 1950, Problems of Paleontology, Leningrad State University, vol. 1, pp. 243-263, 7 pls.; Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst., Minister. Geol. i Ochrany Nedr, nov. ser., vol. 8, pp. 111-128, pls. 60-67, 89; Lecompte, 1951, Inst. Roy Sci. Nat. Belgique, Mém. 116, p. 152; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F131; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 129; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 436, pl. 31, figs. 7, 8; pl. 33, fig. 10; pl. 34, fig. 1; pl. 36, fig. 6.

Type species, *Stromatopora granulata* Nicholson, 1873, Ann. Mag. Nat. Hist., ser. 4, vol. 12, p. 94, pl. 4, fig. 3 (Middle Devonian, Arkona, Ontario).

Coenosteum laminar to massive; astrorhizae may be present or absent; tissue of skeleton fibrous, with fine to coarse tubules, not maculate; pillars regular to irregular with more extensive development of ring-pillars than in *Stictostroma*; one Missouri specimen with superposed ring-pillars, but pillars generally not superposed; dissepiments common but not so frequent as in species from other regions.

Stromatoporella foraminosa Birkhead, n. sp. Pl. 3, fig. 2; Pl. 11, figs. 1a, b

Coenosteum.—Massive, specimen collected has half-cylinder shape, 4.3 cm high, 18 cm long, and 11 cm at widest part; surface regular but extensively covered with mamillae; mamillae 0.5 to 1.0 mm in diameter; astrorhizae absent; latilaminae well developed, not uniform in thickness, 1 to 3 mm thick, four or five in 1 cm.

Vertical section.—Tissue finely fibrous, tubulose, with vacuities in upper and lower parts of the pillars and laminae; laminae regular, turn up gently into mamillar columns, thin, consist of one layer of tissue confluent with the pillars, 0.04 to 0.14 mm thick, averaging 0.08 mm, nine to eleven in 2 mm; pillars superposed but rarely for more than between two laminae; pillars spaced closer together in the columns and are divergent, spool-shaped, a few Y-shaped, 0.05 to 0.21 mm thick, averaging 0.08 mm, six to eight in 2 mm, ring-pillars formed by upturns of laminae difficult to detect without careful observation; galleries oval, oblong, to rectangular, height 0.07 to 0.67 mm, averaging 0.33 mm; no pseudo-zooidal tubes; large foramina through laminae connect galleries; dissepiments rare.

Tangential section.—Tissue fibrous, tubulose, but approaching compactness, with vacuities in pillars and laminae which give a pseudo-maculate appearance to some areas; pillars 0.05 mm to 0.11 mm in diameter, averaging 0.10 mm, round, some ring-pillars with outside diameter of 0.20 to 0.33 mm, averaging 0.23 mm and inside diameter averaging 0.10 mm, pillars from 0.11 to 0.14 mm apart, a few connected by dissepiments; mamillar columns surrounded by annuli of laminae, diameter of columns varies from

0.98 to 2.55 mm; there are circular spaces within some of the annuli which are abnormally large foramina through the laminae, foramina measure from 0.04 to 0.24 mm in diameter, averaging 0.14 mm; galleries anastomose around the pillars; astrorhizae absent; annuli of laminae which mark locations of columns are about 2.2 mm apart (center to center).

Discussion.—Distinctive features of *Stromatoporella foraminosa* are the well-formed mamillar columns, the large amount of vacuities in the tissue, and the abnormally large foramina of the laminae from which the trivial name is derived. This species is similar to *Stromatoporella parasolitaria* Galloway and St. Jean, but astrorhizae are absent, and foramina are more common than in *S. parasolitaria*. It also resembles *Anostylostroma microcolumnare* Galloway and St. Jean in larger skeletal structures, but laminae are more closely spaced, pillars are not so thick, galleries are wider than they are high (not higher than wide as in *A. microcolumnare*), and ring-pillars are present in *S. foraminosa*.

Occurrence.—*Stromatoporella foraminosa* was one of the stromatoporoids found in the Snyder Creek Shale. There is some question as to whether the specimen found grew in place or was eroded from the Callaway Formation. It was found loose but conformable to the bedding of the Snyder Creek Shale and was in a basal, limy shale facies of that formation.

Holotype.—North Carolina University Paleontological Collections, slides 310-31, 312-03. Cat. No. 3628; in part, Univ. of Mo. Cat. No. 14721.

Stromatoporella congregabile Birkhead, n. sp.

Pl. 9, figs. 3a, b

Coenosteum.—Massive, 7 cm high and 20 cm in diameter; weathered surface has anastomosing and vermicular ridges and grooves, pitted, some pits are extensions of ring-pillars; some areas with wider grooves may indicate astrorhizae, but astrorhizae vague; no mamelons; papillae present; latilaminae not seen on weathered surface, but lighter and darker bands seen on polished vertical section, bands vary considerably in thickness, from 0.50 to 5.00 mm, not continuous across coenosteum.

Vertical section.—Tissue fibrous with transverse tubules through both laminar and pillar tissue; laminae regular to irregu-

lar, vary in spacing, in areas of regular spacing are from 0.04 to 0.20 mm thick, averaging 0.08 mm, eight to ten in 2 mm, lighter in color than pillars; pillars short, thick, some spool-shaped, frequently superposed, from 0.04 to 0.20 mm thick, averaging 0.10 mm, spacing of pillars not regular, six or seven in 2 mm, pillars bent and irregularly shaped near base of coenostea, some pendant in vertical section, ring-pillars not readily seen in vertical section; galleries oval and subrectangular in shape, some connected by foramina and U-shaped due to pendant pillars, gallery breadth varies considerably, from 0.10 to 1.00 mm, averaging 0.26 mm, height from 0.10 to 0.28 mm, averaging 0.16 mm; in some parts of the vertical section laminae turn upward into mamelon structures, but no mamelon tubes present; dissepiments are built across some of the larger galleries but are not common.

Tangential section.—Pillars round, coalescent, averaging 0.17 mm in diameter; ring-pillars, averaging 0.33 mm outside diameter and 0.10 mm inside diameter, are located near areas of astrorhizae; astrorhizae occur sporadically, consist of short, forked, radiating canals, with or without central tube, astrorhizae average 2.30 mm in overall diameter; laminae marked in tangential section by lighter bands of tissue which bend eccentrically around astrorhizae, may denote low mamelons on which astrorhizae are located; a few pillars connected by dissepiments; galleries vermicular and anastomosing; tissue occupies from 50% to 95% of a tangential section.

Discussion.—Variable spacing of pillars and laminae of the skeleton (which gives a banded appearance to the vertical section and makes layers of dense tissue followed by layers containing more gallery space), and small, sporadic astrorhizae with a few ring-pillars concentrated near them are characteristics of *Stromatoporella congregabile*. One of the coenostea consists of a flat, laminar portion at the base, 3 mm thick, which has mamelons and resembles *Stictostroma planulatum* Birkhead, n. sp. in form; growth continues above the base in four successive bands of this type, after which the remainder of the coenosteum is thick, massive, and is not conspicuously mamillate. The denseness of tissue varies from thick development, in which areas little gallery space is present, to more open (gallery space) development. Areas of dense tissue appear to merge into areas of less dense tissue without interrup-

tion. The basal layer which contains the greatest development of mamelons is composed of more compact tissue (not as fibrous as the tissue of *Stictostroma planulatum*). *Stromatoporella congregabile* is similar to *Stromatoporella cryptoannulata* Galloway and St. Jean, but pillars are not so thick, astrorhizae are larger, mamelons are not so frequent, and multiple tubes are not present in mamelons as they are in *S. cryptoannulata*. The massive part of the coenosteum of *S. congregabile* is similar to *Stictostroma jeffersonvillense* Galloway and St. Jean, but the surface is not mamillate, laminae are more variable in thickness, mamelon columns are not developed, and dissepiments are not so common as they are in *Stictostroma jeffersonvillense*.

Occurrence.—Common in the Callaway Formation at localities A and G. Some coenostea are intergrown with layers of *Clathrocoilon subclathrata* Galloway and St. Jean and *Stromatopora granata* Birkhead, n. sp. It is also associated with *Amphipora ramosa* (Phillips) and *Stachyodes spongiosum* Stearn, *Favosites* sp., and small horn corals. Reference is made to these associations by the trivial name.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-42, 100. Cat. No. 3635; paratypes, slides 310-38, 39, 40, 41.

Stromatoporella turbata Birkhead, n. sp.

Pl. 10, figs. 2a, b, c, d

Coenosteum.—Low dome-shaped, convexo-concave, basal part concave; height 1 cm, diameter of incomplete specimen 7.5 cm; surface mamillate, weathers to irregular ridges and depressions; mamelons 2 to 3 mm in diameter, 1 mm in height but appear higher as coenosteum weathers from around mamelons, mamelons spaced 5 to 7 mm from center to center; no astrorhizae, but short canals and central tubes can be seen with hand lens on mamelons; latilaminae present, composed of light and dark bands which are not regular and can be seen on polished vertical surface, five or six latilaminae in 1 cm; peritheca present.

Vertical section.—Tissue compact with transverse and anastomosing tubules; laminae irregular, formed in part in cystlike fashion, tissue more dense at margins of laminae, laminae thicker in upturns of mamelons and in irregular bands throughout section,

thickness variable, from 0.04 to 0.39 mm, averaging 0.07 mm, six to nine in 2 mm; dissepiments common; pillars straight, spool-shaped, but also inclined and irregular, a few superposed, thicker in mamelons, from 0.06 to 0.17 mm in diameter, averaging 0.08 mm, four to seven in 2 mm, ring-pillars present but not conspicuous, formed from upturns of laminae; galleries irregularly shaped, from oval to rectangular, height 0.07 to 0.35 mm, averaging 0.18 mm, breadth from 0.08 to 2.10 mm, averaging 0.56 mm.

Tangential section.—Tissue finely fibrous in pillars with included tubules, pillars round, anastomosing, some connected with dissepiments, many round pillars show circular clear spots of calcite because of the transection of the tubules in the tissue, pillars range from 0.13 to 0.28 mm in diameter, averaging 0.18 mm, pillars about 0.17 mm apart if not anastomosing, ring-pillars present but obscure, outside diameter 0.20 to 0.33 mm, inside diameter 0.10 to 0.14 mm; galleries anastomose around the pillars; from one to six tubes 0.08 to 0.29 mm in diameter, averaging 0.17 mm, occur in the mamelons, tubes round to oval in shape; mamelons indicated by from three to five annuli of laminae in tangential section; astrorhizae not apparent and, if present, would be on the mamelons; tissue and gallery space is about equal.

Discussion.—Development of the mamelons, irregular arrangement of laminae, great variance in thickness and spacing of laminae, coarse tubules in the tissue, and ring-pillars are distinctive features of *Stromatoporella turbata*. This species is similar to *Stictostroma jeffersonvillense* Galloway and St. Jean, but pillars and laminae are more irregularly spaced and have a wider range of thickness, tubules in the tissue are coarser, and ring-pillars are present. It resembles *Stromatoporella excellens* (Galloway and St. Jean), but *S. excellens* has much better developed ring-pillars. The trivial name refers to the overall irregularity of the pillars and laminae.

Occurrence.—Rare in the Callaway Formation at locality G; found in dense, dark gray limestone.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-43, 45. Cat. No. 3636; paratype, slide 310-44.

***Stromatoporella indubia* Birkhead, n. sp.**

Pl. 3, fig. 5; Pl. 4, fig. 3; Pl. 10, figs. 1a, b, c, d

Coenosteum.—Massive, an incomplete specimen is 12 cm high and 20 cm in diameter; surface irregular, mamillate, contains depressions and ridgelike protuberances; mamelons absent; mamillae present, less than 1 mm in diameter generally, a few reach 1 mm diameter; astrorhizae cannot be seen distinctly on weathered surface but can be seen on freshly broken surfaces, have two to five central tubes and radiating, branching canals, overall diameter 0.5 to 0.7 cm, about 0.5 cm apart; latilaminae appear as lighter and darker bands, 1 to 5 mm thick, not regularly spaced and appear discontinuous.

Vertical section.—Tissue dense, granular, with many anastomosing tubules, pillars finely fibrous but fibers mostly destroyed by alteration; laminae irregular and contain vertical and anastomosing tubules, bend upward into mamillar columns, are thicker near the columns, vary from 0.06 to 0.35 mm in thickness, averaging 0.10 mm, seven to nine in 2 mm; pillars are short, spool-shaped, irregular, mostly confined between two laminae, a few superposed, ring-pillars present but obscure, regular pillar diameter from 0.08 to 0.24 mm, averaging 0.14 mm, ring-pillars from 0.35 to 0.70 mm, averaging 0.45 mm outside diameter, a few scattered ring-pillars have thick margins due to upturns of thick laminae, five to seven pillars occur in 2 mm; galleries irregularly oval to subrectangular, breadth 0.10 to 0.87 mm, averaging 0.35 mm, height from 0.07 to 0.36 mm, averaging 0.17 mm; no pseudozooidal tubes due to superposed galleries, but tubes in mamillar columns resemble zooidal tubes; dissepiments uncommon, occur in the astrorhizal tubes.

Tangential section.—Tissue granular, with anastomosing tubules, appears porous, pores are cross sections of tubules; pillars round, coalescing, some with central lumen from 0.01 to 0.03 mm in diameter, some pillars connected by dissepiments, pillars not coalescent average about 0.11 mm apart, regular pillars from 0.10 to 0.28 mm in diameter, averaging 0.18 mm, ring-pillars from 0.18 to 0.42 mm overall diameter, averaging 0.25 mm, inside diameter averages 0.13 mm; galleries vermicular, anastomosing; astrorhizae consist of three or four central tubes, oval to oblong in shape, with

short, thick, anastomosing canals radiating from the center, average diameter of the canals 0.18 mm, overall diameter of astrorhizae about 4.8 mm and astrorhizae spaced about 7.4 mm apart.

Discussion.—Distinctive features of *Stromatoporella indubia* are the small, clear lumina in pillars (not ring-pillars), the irregular laminae and pillars, obscurity of the ring-pillars. This species is similar to *Stromatoporella granulata* (Nicholson), but has no median clear line in the laminae, has fewer dissepiments, and ring-pillars are not so conspicuous. The mamillar columns are smaller than those of *Stromatoporella cryptoannulata* Galloway and St. Jean.

Occurrence.—Occurs at one horizon of the Callaway Formation, locality A; same horizon as *Stictostroma planulatum* Birkhead, n. sp.; coenostea are pure calcium carbonate but are enclosed in a dark, grayish-yellow, argillaceous limestone.

Holotype.—North Carolina University Paleontological Collections, slides, 310-46, 47. Cat. No. 3637.

***Stromatoporella ozoraensis* Birkhead, n. sp.**

Pl. 3, figs. 7a, b; Pl. 9, figs. 4a, b

Coenosteum.—Flat, cake-shaped; fragment of a specimen is 8 cm long, 1.5 cm high and 5.5 cm at widest part; surface pitted and papillate; ring-pillars at surface show as larger pits; papillae numerous; mamelons, astrorhizae, and latilaminae absent.

Vertical section.—Tissue fibrous and minutely porous transversely; laminae regular, turn up abruptly at right angles to form superposed ring-pillars, laminar tissue with straight, transverse tubules, most laminae with clear median line, laminae 0.06 to 0.14 mm thick, averaging 0.08 mm, seven to nine in 2 mm; pillars short, few superposed, ring-pillars also superposed to form ring-pillar columns, incomplete pillars with connecting dissepiments present in some areas, regular pillars 0.04 to 0.25 mm in diameter, averaging 0.13 mm, ring-pillars 0.28 to 0.42 mm in outside diameter, averaging 0.35 mm; galleries subrectangular in form, length 0.11 to 1.00 mm, averaging 0.42 mm, height 0.10 to 0.34 mm, averaging 0.21 mm; dissepiments present but not common except in ring-pillar columns, occur in some of the galleries, are horizontal to low oblique, low arched, convex upward.

Tangential section.—Pillars fibrous and porous, laminar tissue more dense, minutely porous; distance between pillars averages 0.14 mm, pillars round, vermicular, and rings, round pillars more abundant than ring-pillars, diameter of regular pillars 0.10 to 0.27 mm, averaging 0.21 mm, outside diameter of ring-pillars 0.28 to 0.50 mm, averaging 0.42 mm, inside diameter from 0.10 to 0.20 mm; galleries anastomose around pillars; no astrophorae; tissue comprises 50% of the section.

Discussion.—The most notable characteristic of *Stromatoporella ozoraensis* is the superposition of the ring-pillars. The species is similar to *Stromatoporella granulata* (Nicholson), but the pillars, both regular and ring-pillars, are more frequently superposed, and the tissue of *S. ozoraensis* is more fibrous and not so tubular; similar to *Stromatoporella tuberculata* Nicholson except dissepiments connecting pillars are not so common, and ring-pillars are more frequently superposed; similar to *Gerronostroma insolitum* (Parks), but laminae are spaced closer, ring-pillars are of larger average diameter and more profusely developed. The vermicular shape of some of the pillars, and fine, transversely fibrous tissue of the solid pillars are characteristics which are similar to those of the genus *Anostylostroma*.

Thus, *Stromatoporella ozoraensis* has features of *Anostylostroma*, *Stictostroma*, and *Gerronostroma* but was placed in the genus *Stromatoporella* because of the extensive development of ring-pillars and minutely tubular tissue. The trivial name refers to the locality at which the species was collected.

Occurrence.—Rare in the Grand Tower Formation at locality O; found in white crystalline limestone with *Stictostroma ozarkense* Birkhead, n. sp.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-48, 49. Cat. No. 3638; paratype, slide 310-50.

***Stromatoporella cryptomamillata* Birkhead, n. sp.**

Pl. 9, figs. 2a, b

Coenosteum.—Flat, thin, undulating; 7.0 mm high, tapering to a thin edge, one specimen 12.5 cm in diameter; surface with mamelons 2 to 3 mm in diameter and 1 to 3 mm high, 5 to 7 mm from center to center, four in one sq. cm; papillate; astrophorae or latilaminate not visible on coenosteum; peritheca present.

Vertical section.—Tissue fibrous, transversely tubulate; basal part of skeleton consists of a layer 0.5 to 1.0 mm thick of small, circular galleries surrounded by tissue which is darker than that of the remainder of the section; tissue is thickly developed above the basal layer; pillars and laminae indistinct, becoming more regular and distinct in areas immediately adjacent to the mamelons, although mamelons have little gallery space; laminae in intermamelon spaces above thick basal tissue are 0.04 to 0.13 mm thick, averaging 0.08 mm, laminae curve up into mamelons; pillars 0.04 to 0.23 mm thick, many have darker tissue than laminae; galleries small, sparse, oval to elongate in the intermamelon areas, 0.06 to 0.17 mm high and 0.06 to 1.00 mm broad; superposed, branching, astrorhizal tubes present in mamelons, average 0.10 mm in diameter.

Tangential section.—Pillars mostly round, a few ring-pillars present, 0.40 mm outside diameter, 0.10 mm inside diameter, centers of regular pillars darker in color than surrounding tissue; pillar and laminar tissue difficult to distinguish except where pillars have dark centers; galleries mostly irregular, gallery spaces arranged in a ring pattern around mamelons; astrorhizae present on mamelons, with central tube 0.10 mm in diameter and one or two short, radiating, nonbranching canals, with largest diameter of 0.10 mm, overall diameter of astrorhizae 1.0 mm; tissue occupies 90% of the area of the section except in the intermamelon regions where tissue is about 80% of the section.

Discussion.—*Stromatoporella cryptomamillata* is characterized by the flat coenosteum with mamelons, the concentration of gallery spaces in intermamelon areas, the dense tissue filling of the mamelons, small astrorhizae on the mamelons, and thick-walled ring-pillars. The species is similar to *Stictostroma planulatum* Birkhead, n. sp. but has astrorhizae on the mamelons, mamelons contain less gallery space, and mamelons are not so strongly developed as those of *Stictostroma planulatum*. The trivial name refers to the filling in of the intermamelon areas with widely spaced laminae, which in effect hides the lower parts of the mamelons seen at the surface of a coenosteum.

Occurrence.—Common in the Callaway Formation at locality G.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-51, 52. Cat. No. 3639; paratype, slide 311-02.

Family **ACTINOSTROMATIDAE** Nicholson, 1886

Family Actinostromidae Nicholson, 1886, *Palaeontographical Soc.*, vol. 39, p. 74, 75.

Family Actinostromatidae Stechow, 1922, *Archiv. Naturg.*, Abt. A, vol. 88, Hef 3, p. 151; Lecompte, 1956, in Moore, *Treatise on Invert. Paleont.*, pt. F, p. F127; Galloway and St. Jean, 1957, *Bull. Amer. Paleont.*, vol. 37, No. 162, p. 148; Galloway, 1957, *Bull. Amer. Paleont.*, vol. 37, No. 164, p. 437.

Coenosteum laminar or massive, rarely cylindrical, composed of definite laminae and of long continuous, or superposed short pillars; laminae regular or irregular, of sheetlike structure or radial processes, with secondary thickening tissue; tissue compact, fibrous, porous, or vacuolate, but not maculate; galleries usually superposed; dissepiments rare to frequent; astrorhizae present or absent.

Genus **TRUPETOSTROMA** Parks, 1936

Kühn, 1939, in Schindewolf, *Handbuch Paläozoologie*, Bd. 2A, p. A44, fig. 61; Lecompte, 1952, *Inst. Roy. Sci. Nat. Belgique, Mém.* 117, p. 219; Lecompte, 1956, in Moore, *Treatise on Invert. Paleont.*, pt. F, p. F132; Galloway and St. Jean, 1957, *Bull. Amer. Paleont.*, vol. 37, No. 162, p. 158; Galloway, 1957, *Bull. Amer. Paleont.*, vol. 37, No. 164, p. 439, pl. 31, fig. 11; pl. 34, fig. 4; Yavorsky, 1963, *Gosudarstvennyi Geologicheskyy Komitet S.S.S.R. Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst. (V.S.E.G.E.I.)*, new ser., vol. 87, p. 66.

Type species (originally designated), *Trupetostroma warreni* Parks, 1936, *Univ. Toronto Studies. Geol. Ser.*, No. 39, p. 52, pl. 10, figs. 1, 2 (Middle Devonian, Great Slave Lake, Canada).

Coenosteum massive; laminae regular or irregular, sometimes with clear or dark middle line thickened on both sides with secondary tissue; pillars more strongly developed than laminae, round, regularly superposed; tissue compact, vacuolate, not maculate; dissepiments absent to abundant; astrorhizae present or absent.

Trupetostroma ideale Birkhead, n. sp. Pl. 3, fig. 6; Pl. 12, figs. 2a, b

Coenosteum.—Massive globular form; one specimen 5 cm high and 4 cm in diameter; surface even, mamelons and papillae not apparent; astrorhizae present, with central tube and radiating canals, 2.0 mm in overall diameter, 4 to 6 cm from center to center; latilaminae difficult to see, not well developed.

Vertical section.—Tissue compact with small, widely spaced

vacuoles; laminae regular, with light median layer of dense tissue, but light median layer not present in all laminae, laminae 0.03 to 0.13 mm thick, averaging 0.06 mm, nine to eleven in 2 mm; pillars confined between two laminae, short, some spool-shaped, many superposed, 0.05 to 0.17 mm wide, averaging 0.11 mm, seven to nine in 2 mm; galleries oval to rectangular, most superposed, height 0.09 to 0.22 mm, averaging 0.15 mm, breadth 0.07 to 0.49 mm, averaging 0.21 mm; dissepiments rare; mamelons are gentle upturns of the laminae, pillars diverge in the upturns; astrorhizal tubes more circular in cross section than galleries, average 0.20 mm in diameter; basal peritheca present, of darker, more compact tissue than remainder of skeleton.

Tangential section.—Tissue compact, tissue of upper and lower layers of laminae and of pillars is vacuolate; pillars round, coalescent form chainlike circles and rectangles, structures resembling irregular radial processes extend from some pillars, central lumen in many pillars (maybe vacuities), average pillar diameter 0.09 mm, if not coalescing are 0.10 mm apart; galleries irregularly rectangular to oval, anastomose, 0.09 to 0.14 mm in diameter; three to five tubes in mamelons, oval, coalesce, large, 0.20 to 0.39 mm in diameter, averaging 0.35 mm; astrorhizal canals 0.09 to 0.14 mm wide, appear short and thick in tangential section, but this is probably due to curving of the canals; space divided equally between galleries and tissue.

Discussion.—Characteristic features of *Trupetostroma ideale* are the light median layer of tissue in part of the laminae, small, sporadic vacuoles in the tissue, and the large tubes in the mamelons. There is a large tube about 0.40 mm in diameter which occurs sporadically in the coenosteum. The species differs from *Trupetostroma warreni* Parks in that the laminae are thicker, the light median line of the laminae is not so pronounced, pillars and laminae are spaced more closely, the galleries are not so high, and mamelons are not so conspicuous on the coenosteum. In poorly preserved areas where microlaminae (light median lines of the laminae) are destroyed, a false impression of long, continuous pillars instead of short, superposed ones is obtained.

Occurrence.—Common in the Callaway Formation at locality N.

Holotype.—North Carolina University Paleontological Collections, slides 310-53, 54. Cat. No. 3640; in part, Univ. of Mo. Cat. No. 14727.

Trupetostroma vesiculosum (Stearn)

Pl. 11, figs. 2a, b

Anostylostroma vesiculosum Stearn, 1961, Jour. Paleont., vol. 35, No. 5, p. 935, pl. 105, figs. 3, 4, 5 (?); Stearn, 1963, Jour. Paleont., vol. 37, No. 3, p. 655, pl. 85, figs. 1, 2.

Coenosteum.—Massive, cake-shaped form with undulating surface; an incomplete specimen which forms the substrate for a massive coenosteum of *Anostylostroma callawayensis* Birkhead, n. sp. is 2 cm high and 8.5 cm in diameter; surface features covered by *A. callawayensis*, but from polished vertical section surface inferred to have mamelons about 1.0 mm high and spaced about 3 to 4 mm apart; latilaminae vague, but light and dark irregular bands present on vertical polished surface, 0.70 to 1.50 mm thick; division between *Trupetostroma vesiculosum* and *Anostylostroma callawayensis* marked by about 1 mm of darker colored laminae of *T. vesiculosum*.

Vertical section.—Tissue compact but with tubules and a few vacuities; laminae regular, with dark median line, 0.06 to 0.14 mm thick, averaging 0.11 mm, eight or nine in 2 mm, turn up into mamelons and thicken; pillars dominant over laminae, long, diverge away from mamelons, average 0.13 mm in width, seven in 2 mm; galleries oval to rectangular, 0.12 to 0.40 mm in breadth, averaging 0.14 mm, height of galleries about equal to width; large astrorhizal tubes converge upward into mamelons; dissepiments are so profusely developed in galleries and mamelon tubes the vertical section shows dissepiments as a major structural feature.

Tangential section.—Tissue compact, minutely tubulate; pillars round, averaging 0.17 mm in diameter and 0.13 mm apart, some with center of darker tissue; annuli of laminae surround mamelons; mamelons with central area of circular tubes which can hardly be distinguished from galleries; galleries connected, some oval in shape; dissepiment tissue obscures gallery space and makes thin section appear dark.

Discussion.—*Trupetostroma vesiculosum* (Stearn) is characterized by short but superposed, spool-shaped pillars and dark median layer of tissue in the laminae, but the most striking feature is the

profuse development of dissepiments; dark median layer of the laminae is composed of same tissue as dissepiments. *T. vesiculosum* is similar to *Trupetostroma adriani* Birkhead, n. sp. but has greater development of dissepiments, and pillars are not so closely spaced. This species was placed in the genus *Trupetostroma* because of the tubulose tissue and dominance of pillars over laminae. The difference in appearance of the figures of the Missouri specimens and of the holotype figures is largely due to the difference in preservation of the dissepiments. In the Missouri specimens the dissepiments are so darkly preserved the laminae are difficult to observe in vertical section.

Occurrence.—Rare in the upper part of the Callaway Formation, locality A; overgrown by *Anostylostroma callawayensis* Birkhead, n. sp.

Hypotypes.—North Carolina University Paleontological Collections, slides 310-55, 56. Cat. No. 3641.

***Trupetostroma adriani* Birkhead, n. sp.**

Pl. 11, figs. 3a, b, c, d

Coenosteum.—Occurs in irregular nodular masses and in elongate hemispheres; average specimen 15 cm long, 9.5 cm wide, and 6 cm high; surface irregular with low nodal protrusions which show concentric rings of laminae in weathered areas; papillate; astro-rhizae present, symmetrical, circular, canals do not bifurcate, are of equal length and arranged radially, 5 mm from center to center, but not regularly distributed over entire surface; latilaminae vague.

Vertical section.—Tissue compact, with vacuities; laminae consist of median, dark microlamina with a layer of vacuolate tissue above and below, laminae 0.04 to 0.21 mm thick, spool-shaped, most are superposed, tissue confluent with outer layers of laminae, vacuolate among margins, 0.07 to 0.25 mm thick, averaging 0.13 mm, six to eight in 2 mm, diverge in mamelons; galleries small, oval, some superposed, height 0.08 to 0.24 mm, averaging 0.10 mm; mamelon tubes 0.14 to 0.42 mm in diameter; dissepiments rare, but microlaminae cross galleries and mamelon tubes.

Tangential section.—Tissue compact with vacuoles which give a flocculent appearance to tissue in places; pillars anastomose, 0.09 to 0.25 mm in diameter, averaging 0.14 mm; tubes in mamelons are circular to oval, 0.18 to 0.42 mm in diameter; annuli of lami-

nae mark positions of mamelons; galleries oval circular, some elongate; about 80% of the section is tissue.

Discussion.—Distinctive features of *Trupetostroma adriani* are the vacuoles in the tissue which sometimes gives a maculate appearance to the tissue, the tabulate appearance of the mamelon tubes due to microlaminae crossing them, and small amount of gallery space. The species is similar to *Trupetostroma bassleri* Lecompte but differs in that the mamelon tubes consist of only one large tube with few branches and it does not have the dissepiments of *T. bassleri*. It is also similar to *Trupetostroma* (?) *ravicystosum* Galloway and St. Jean, but that species does not have the pseudo-zooidal tubes of *T. adriani*.

Occurrence.—Abundant near top of the Callaway Formation in an argillaceous limestone at locality B. The stromatoporoids can be knocked from the matrix. With short exposure to weather the limestone matrix disintegrates, leaving the more dense and purer calcium carbonate coenostea. *T. adriani* is found mixed with *Favosites* sp. They may be part of a channel fill. Parts of the same coenosteum are sometimes differently preserved, with darker tissue occurring in places. The dark material may be finely disseminated pyrite. The trivial name refers to the Adrian Brothers Quarry where the specimens were collected.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-58, 60. Cat. No. 3642; paratypes, slides 310-57, 59; 312-04.

Trupetostroma kennissoni Birkhead, n. sp.

Pl. 12, figs. 1a, b

Coenosteum.—Massive, hemispherical in shape; height of average specimen 11.5 cm, diameter 11.0 cm; surface irregular, papillate, with pits and grooves from astrorhizal canal system; mamelons absent; complete astrorhizae not seen on surface, but long, branching canals conspicuous, some of them 5 mm long; latilaminae not conspicuous on weathered specimens, but on polished vertical section there are discontinuous light and dark bands of laminae which vary from 1.0 to 2.0 mm in thickness.

Vertical section.—Tissue badly altered, compact, tubulate, pillar and laminar tissue confluent; laminae indicated by arrangement of galleries in almost regular horizontal lines; faint traces of micro-

laminae can be observed; laminae 0.06 to 0.20 mm thick, six to eight in 2 mm; pillars same thickness as laminae, short; galleries numerous but small, irregularly elongate to oval, usually about as high as broad, 0.10 to 0.26 mm broad, averaging 0.16 mm; segments of astrorhizal canals up to 2.0 mm long present, no axial tubes in astrorhizae indicated in vertical section, cross sections of astrorhizal canals are large circular spaces which stand out from galleries in having regular shape and in being larger, averaging 0.35 mm in diameter; few dissepiments present, some in astrorhizal canals.

Tangential section.—Tissue tubulate, has maculate appearance in parts of the section because of the cross-sectioning of vertical tubules; pillars round, vermicular, some coalescing to form rings, some round pillars with central lumen, pillars 0.10 to 0.16 mm in diameter; galleries circular to irregular in shape, anastomose in some areas of the section, average 0.08 mm in breadth; astrorhizae conspicuous in tangential section, axial tube vague, if present is small, about 0.30 mm in diameter, large, bifurcating canals radiate from central area, 0.40 mm in width, reaching 4 to 5 mm in length, form astrorhizal network over surface; dissepiments common in astrorhizal canals, resemble tabulae; tissue to gallery space is about equal.

Discussion.—Distinctive features of *Trupetostroma kennisoni* are the large astrorhizae with small central tube, tubulate tissue, horizontal arrangement of galleries which distinguish the laminae, lack of clear or dark median layer of tissue in laminae, and dissepiments which occur in astrorhizal canals but not in galleries. The species is similar to *Trupetostroma coalescens* Galloway and St. Jean, but astrorhizae are larger, mamelons are not developed to the extent of *T. coalescens*. If the tissue were truly maculate, *T. kennisoni* would be placed in the genus *Ferestromatopora* or *Stromatopora*.

Occurrence.—Abundant in upper part of the Callaway Formation at localities E and H; found in arenaceous and somewhat argillaceous limestone which contains pyrite. Coenostea are profusely scattered in what seems to be a channel through the limestone. The trivial name refers to the Kennisson Quarry near Holt's Summit, Mo. where the species is very abundant.

Types.—Holotype, North Carolina University Paleontological

Collections, slides 310-62, 63. Cat. No. 3643; paratypes, slides 310-61, 64, 86.

Family **STROMATOPORIDAE** Winchell, 1867

Family *Stromatoporidae* Winchell, 1867, Amer. Assoc. Adv. Sci., Proc., p. 98; Nicholson, 1886, Palaeontographical Soc, vol. 39, p. 74; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, p. A44; Lecompte, 1956, in Moore, Treatise Invert. Paleont., pt. F, p. F133; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 163; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 445.

Coenosteum massive to laminar, composed of latilaminae, laminae, and short and long pillars; or short interlaminar spaces more or less filled with secondary tissue; tissue finely or coarsely maculate and amalgamated, maculae may or may not be horizontally and vertically or vertically arranged; pseudozooidal tubes, astrorhizae, and mamelons common.

Genus **FERESTROMATOPORA** Yavorsky, 1955

Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 446, pl. 36, figs. 1, 2, 4.

Type species (first species, designated by Galloway, 1957) *Ferestromatopora krupennikovi* Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst., Minister. Geol. i Ocherany Nedr. nov. ser., vol. 8, p. 109, pl. 58, figs. 1-5 (Middle Devonian, Kuznetz Basin, Tyrgan, Russia).

Coenosteum massive, the Missouri specimen cone-shaped; latilaminar; pillars and laminae indefinite; tissue amalgamate, composed of fine to coarse maculae; galleries oval to subrectangular, some form short pseudozooidal tubes; mamelons absent; astrorhizae may or may not be present.

Ferestromatopora turbinata Birkhead, n. sp.

Pl. 12, figs. 3a, b

Coenosteum.—Cone-shaped, 6.5 cm high and 7.5 cm in diameter at the base; surface pitted, may be borings of another animal, pits 1 to 5 mm in diameter; no mamelons or astrorhizae or surface; papillae are protrusions of pillars, give a sand grain appearance to surface; latilaminae seen on base of specimen, 1 to 3 mm thick, seven latilaminae in 1 cm in perimeter area to three in 1 cm towards the center of the base of the cone.

Vertical section.—Tissue coarsely maculate, maculae not uni-

form, from 0.02 to 0.09 mm in diameter; laminae regular over parts of section, taking on some of the attributes of *Stromatopora*, and irregular over other parts; microlaminae, made of horizontal rows of maculae, are developed in areas of regular laminae, microlaminae 0.026 mm thick, regular laminae 0.08 to 0.23 mm thick, seven in 2 mm; pillars irregular, usually confined to one interlaminar space, but a few are superposed through two or three interlaminar spaces, pillars same thickness as laminae, laminar and pillar tissue confluent in areas where regular development of laminae is absent; coarse maculae are scattered in the tissue, separated by spaces void of tissue within pillars and laminae; galleries irregular in shape, some connected with foramina, but pseudozooidal tubes rare, galleries 0.08 to 0.53 mm broad, averaging 0.37 mm, and 0.06 to 0.23 mm high, averaging 0.18 mm.

Tangential section.—Pillars vermicular, elongate, some connected to form rings, average 0.17 mm in diameter, those not connected 0.10 to 0.12 mm apart; galleries irregularly elongate, vermicular, anastomose, 0.11 mm broad; tissue coarsely maculate, hollows between maculae conspicuous, tissue has flocculent aspect; astrorhizal structures not distinct, but thick-walled, circular tube-like structures 0.26 mm in diameter occur sporadically in the section; tissue and gallery space each occupy about 50% of the section.

Discussion.—The cone-shaped coenosteum (the character for which the species is named), absence of astrorhizae and mamelons, coarsely maculate tissue, and areas of regular and irregular laminae and pillars are distinctive features of *Ferestromatopora turbinata*. The species is similar to *Ferestromatopora tyrganensis* Yavorsky but has some areas of definite laminae and pillars and a few pseudozooidal tubes.

Occurrence.—Rare in the Callaway Formation at locality J. The specimen was not found in place but was picked from a stream bed which crosses the Callaway Formation.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-66, 67. Cat. No. 3644; paratype, slide 310-65; holotype in part, Univ. of Mo. Cat. No. 14729.

Genus **STROMATOPORA** Goldfuss, 1826

Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 91, pl. 11, figs. 15-18; Nicholson, 1891 vol. 44, p. 164, pl. 21, figs. 1-3 (topotypes); Ripper, 1937, Roy. Soc. Victoria, Proc., new ser., vol. 49, p. 184; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, p. A44; Lecompte, 1952, Inst. Roy. Sci. Nat. Belgique, Mém. 117, p. 263, pl. 53, fig. 1; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F123; Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst., Minister. Geol. i Ochrany Nedr, nov. ser., vol. 8, pp. 81-109, pls. 42-57; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 164; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 447, pl. 35, figs. 1-3; pl. 36, fig. 5.

Type species (monotypic), *Stromatopora concentrica* Goldfuss, 1826, Petrefacta Germaniae, 1st ed., vol. 1, p. 22, pl. 8, fig. 5 (Middle Devonian, Gerolstein, Germany).

Coenosteum massive to laminar, with latilaminae; skeleton predominantly tissue; coarsely to finely maculate; galleries small, some superposed, forming pseudozooidal tubes; astrorhizae well developed; mamelons present or absent; dissepiments rare.

Stromatopora congrua Birkhead, n. sp.

Pl. 13, figs. 1a, b

Coenosteum.—Thin to thick layers, from 2 mm to 2.7 cm high, 11 cm wide, and 20 cm long; convex at base and planar on top; surface with low mamelons, 1 mm high, 2 mm in diameter, five in one sq. cm, not covering entire surface; papillate; astrorhizae not visible on hand specimen; latilaminae as seen on polished vertical surface are narrow, consisting of light and dark bands, light bands silicified in some specimens, 14 to 16 in 1 cm.

Vertical section.—Tissue finely maculate; laminae and pillars obscure; galleries scarce, circular in shape, 0.03 to 0.13 in diameter, most clear spaces are cross sections of astrorhizal canals; pseudozooidal tubes rare; maculae arranged in horizontal layers; mamelon columns absent; astrorhizal structures other than cross sections of canals absent although there are conspicuous astrorhizae in tangential sections; tissue of pillars and laminae amalgamated.

Tangential section.—Segments of astrorhizal canals present, 0.08 mm in diameter, without central tubes, canals branch and interconnect between adjacent astrorhizae to form a network, astrorhizae have diameter of about 2.0 mm; galleries small, oval, average 0.06 mm in diameter, scattered, about 0.53 mm apart; pillars 0.15 to 0.30 mm in diameter; about 85% of section is maculate groundmass.

Discussion.—*Stromatopora congrua* is characterized by the small and sparse galleries, small mamelons, interconnecting astrorhizae, and lack of pseudozooidal tubes. The species is similar to *Stromatopora laminosa* Lecompte, but galleries are smaller and not so numerous, pseudozooidal tubes are fewer, and astrorhizal canals are longer and narrower than those of *S. laminosa*.

Occurrence.—Common in the Callaway Formation at locality A.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-71, 72. Cat. No. 3646; paratypes, slides 310-68, 69, 70.

***Stromatopora indistincta* Birkhead, n. sp.**

Pl. 13, figs. 2a, b

Coenosteum.—Massive, forms subhemispherical to flat layers, one specimen eight inches high and two feet in diameter; surface irregular, covered with low ridges and sporadic mamelons; mamelons 1 to 2 mm in diameter, 1 mm high, irregularly spaced, some adjacent to each other, but large areas of coenosteum contain low ridges instead of mamelons; papillae absent; a few astrorhizae can be seen on surface, with branching canals radiating from a central tube, overall diameter 5 mm, 1 cm from center to center, astrorhizal canals interconnect; latilaminae not distinct, but on polished vertical section silicified areas show up as lighter, discontinuous bands; coenosteum dark, reddish-brown to black in color.

Vertical section.—Tissue maculate, pillars and laminae confluent; galleries small, oval or irregular in shape, a few U-shaped, 0.06 to 0.12 mm in diameter; thickness of laminae and pillars difficult to measure because of amalgamation of tissue; galleries occupy little space in the section; superposed astrorhizae present, with axial tube and radiating branches of same diameter, averaging 0.16 mm; cross section of some canals located in astrorhizal columns are thick-walled, round, clear areas with overall diameter 0.04 mm; no dissepiments present.

Tangential section.—Most of section is tissue; galleries small, oval, a few elongate, averaging 0.10 mm in diameter, gallery space only 5 to 10% of section; laminar and pillar tissue hard to differentiate; pillar diameter averages about 0.26 mm; dark, concentric bands which may form rings of laminae around astrorhizae present; astrorhizae with axial tube 0.16 mm in diameter, and radiating,

bifurcating canals 0.16 mm in diameter but tapering to a point; astrorhizae about 8 to 10 mm from center to center, canals form network on surface, dissepiments absent.

Discussion.—*Stromatopora indistincta* is similar to *Stromatopora obscura* Galloway and St. Jean, but the tissue is more coarsely maculate, mamelons are smaller, both in diameter and height, and are not spaced regularly as in *S. obscura*; however, astrorhizae have a greater overall diameter and are more extensively developed. The species is also similar to *Syringostroma astrorhizoides* Birkhead, n. sp., but astrorhizae are not so large and are spaced farther apart than in that species, pillars and laminae are not as definite, and pseudozooidal tubes are not as frequent.

Occurrence.—Abundant in the lower part of the Callaway Formation at locality A. The coenostea are darker than the surrounding limestone. The stromatoporoid material is fractured throughout, and silica has filled the fractures and replaced parts of the stromatoporoid structures. An argillaceous limestone fills some of the larger fractures. The dark color of the coenostea is derived from iron (pyrite), but may also be due in part to carbonaceous material. Corals of the genus *Favosites* were found lying on the surface of some coenostea, and one coenosteum completely enveloped a *Favosites* colony. The indistinct character of skeletal structures, due to poor preservation of the specimens collected, is the feature to which the trivial name refers.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-74, 76. Cat. No. 3645; paratypes, slides 310-73, 75. holotype in part, Univ. of Mo. Cat. No. 14728.

***Stromatopora granata* Birkhead, n. sp.**

Pl. 12, figs. 4a, b

Coenosteum.—Massive, laminar; incomplete specimen 1.3 cm high, 20 cm long, and 13 cm wide; surface with small mamelons, 0.50 mm high, 2 mm in diameter, sporadic; astrorhizae vague; latilaminae composed of darker and lighter bands of laminae, eight in 1 cm.

Vertical section.—Tissue finely maculate; laminar and pillar tissue amalgamated, laminae and pillars indistinct; galleries not numerous, oval to irregular in shape, small, averaging 0.07 mm in breadth; pseudozooidal tubes present but small, about 0.33 mm

in length; mamelon structures not conspicuous in vertical section; some areas of skeleton composed of horizontal layers of maculae which produce microlaminae one macula thick; astrorhizal tubes and branching canals present, some superposed.

Tangential section.—Tissue finely maculate, pillar and laminar tissue indistinguishable except in areas of interconnecting astro-rhizal canals, in which areas pillars anastomose around small oval galleries, pillars in these areas average 0.10 mm diameter; oval galleries average 0.08 mm in diameter; segments of narrow astro-rhizal canals visible, about 0.06 mm in diameter, canals appear to radiate from two or three central tubes 0.06 mm in diameter and divide one or more times, overall diameter of astrorhizae about 2.0 mm; about 85 to 90% of section is tissue.

Discussion.—*Stromatopora granata* is characterized by the finely maculate tissue which gives a fine, granular appearance to sections (the character for which the species is named), microlaminae, development of pseudozooidal tubes, and encrusting nature of the coenosteum. It is similar to *Stromatopora congrua* Birkhead, n. sp., but has more pseudozooidal tubes, maculae are smaller, definite microlaminae are present, astrorhizal canals are narrower, and there is more gallery space in *S. granata*.

Occurrence.—Common in the Callaway Formation at locality G. *Stromatopora granata* is found in layers alternating with *Stromatoporella congregabile* Birkhead, n. sp., and *Clathrocoilonia sub-clathrata* Galloway and St. Jean.

Holotype.—North Carolina University Paleontological Collections, slides 310-77, 78. Cat. No. 3647.

Genus **TALEASTROMA** Galloway, 1957

Taleastroma Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 448, pl. 35, fig. 4.

Type species, *Stromatopora cumingsi* Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 182, pl. 15, fig. 4 (Middle Devonian, Logansport Limestone, Logansport, Indiana).

Coenosteum massive to laminar, latilaminar; tissue maculate; pillars well developed, both long and short, composed of a ring of peripheral maculate tissue and a core of compact tissue; thin laminae separating superposed galleries give tabulate appearance in

pseudozooidal tubes in some species; astrorhizae well developed to absent.

Taleastroma pachytexta (Lecompte)

Pl. 14, figs. 1a, b

Stromatopora pachytexta Lecompte, 1952, Inst. Roy. Sci. Nat. Belgique, Mém. 117, p. 265, pl. 54, fig. 6; pl. 55, figs. 1, 2; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 181, pl. 15, figs. 3a, b.

Taleastroma pachytextum (Lecompte), Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 448.

Coenosteum.—Massive, in flat beds, part of a coenosteum 3 cm high and 8 cm in diameter, but layers extend for two feet; mame-lons absent; surface flat, patterns of anastomosing and round pillars seen on fresh surface; papillae present as projections of pillars on surface; laminae thick, show as dark, narrow bands in weathered vertical surface, interlaminar spaces lighter, combinations of dark laminae and light interlaminar spaces give latilaminar appearance to coenosteum, seven or eight latilaminae in 1 cm.

Vertical section.—Tissue coarsely maculate: laminae and pillars form rectangular network; pillars extend through laminae, both long and short, 0.38 to 6.80 mm long, averaging 3.06 mm, 0.18 to 0.52 mm wide, averaging 0.28 mm, four or five in 2 mm, center with dense tissue; laminae regular, variable in thickness, 0.08 to 0.28 mm thick, five to seven in 2 mm; galleries oval, some elongate, 0.07 to 0.50 mm high, averaging 0.21 mm, 0.14 to 1.54 mm broad, averaging 0.35 mm, some galleries superposed; dissepiments occur rarely in galleries; mame-lons and astrorhizae not apparent in vertical section.

Tangential section.—Coarsely maculate tissue except for centers of pillars which are compact; pillars round, coalescing, some of three-layer construction with center of compact tissue surrounded by lighter ring of compact tissue which, in turn, is surrounded by a darker ring of coarsely maculate tissue, pillars about 0.21 mm apart, if not coalescing, 0.17 to 0.42 mm in diameter, averaging 0.28 mm; astrorhizae absent; galleries vermicular, anastomosing; about 60% of section is tissue and 40% gallery space.

Discussion.—The thick pillars with centers of compact tissue and peripheral areas of maculate tissue are features of *Taleastroma pachytexta* (Lecompte). The Missouri specimens have less distinct

astrorhizae, less conspicuous latilaminae, and slightly thinner pillars than those of the type from Belgium.

Occurrence.—Abundant in the Callaway Formation at locality C. The coenostea occur in a light gray, argillaceous limestone which weathers more readily than the stromatoporoid coenostea. Thus, the coenostea stand out as resistant layers in the outcrop. Associated organic remains are crinoid refuse and the colonial coral *Favosites* sp.

Hypotypes.—North Carolina University Paleontological Collections, slides 310-90, 91; 312-05. Cat. No. 3651; Univ. of Mo. Cat. No. 14724.

Genus **SYRINGOSTROMA** Nicholson, 1875

Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 97, pl. 11, figs. 13, 14; Nicholson, 1891, Ann. Mag. Nat. Hist., ser. 6, vol. 7, p. 326, pl. 10, figs. 8, 9; Girty, 1895, 48th Ann. Rept. State Geol. New York for 1894, vol. 2, p. 289; Parks, 1909, Univ. Toronto Studies, Geol. Ser., No. 6, p. 8; Ripper, 1937, Roy. Soc. Victoria, Proc., new ser., vol. 49, p. 179; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, Bd. 2A, p. A46; Lecompte, 1951, Inst. Roy. Sci. Nat. Belgique, Mém. 116, p. 195; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F131; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 186; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 448, pl. 35, fig. 5; pl. 36, fig. 7; Galloway, 1960, Jour. Paleont., vol. 34, No. 4, p. 631; Stearn, 1962, Geol. Sur. Canada, Dept. Mines Tech. Sur., Bull. 92, p. 11.

Type species, *Syringostroma densum* Nicholson, 1875, Geol. Sur. Ohio, vol. 2, pt. 2, p. 251, pl. 24, fig. 2 (Middle Devonian, Kelleys Island, Ohio).

Coenosteum massive; latilaminae well developed; laminae regular, thick, composed of layers of maculae which form microlaminae; pillars large, short, short but superposed, or long and continuous; tissue of laminae and pillars amalgamated; gallery space largely filled with tissue; astrorhizae conspicuously developed; perithecium may or may not be present.

Syringostroma astrorhizoides Birkhead, n. sp.

Pl. 3, fig. 1; Pl. 4, fig. 1; Pl. 13, figs. 3a, b, c, d

Coenosteum.—Massive, a specimen in limestone two feet in diameter, incomplete specimen is 6 cm high; surface irregular, raised into low domes; papillae 1 mm in diameter cover the surface, closely spaced, some coalescent, form pits on freshly broken

surface; detail of astrorhizae indistinct; latilaminae narrow, composed of light and dark bands of laminae, average 0.50 mm in thickness, 16 in 1 cm, latilaminae weather differentially, producing parallel grooves which follow the planes of the laminae.

Vertical section.—Tissue coarsely maculate; pillars and laminae composed of rows of maculae, giving a reticulate pattern of maculae; laminae regular, composed of microlaminae one macula thick, broadly undulating into mamelons, laminae 0.11 to 0.42 mm thick, averaging 0.19 mm, eight to ten in 2 mm; pillars thick, confluent with laminae, composed of vertical rows of maculae, 0.10 to 0.28 mm thick, averaging 0.21 mm, eight to ten in 2 mm, pillars diverge but are not appreciably thickened in mamelons, pillars short, superposed, some long; long, continuous pillars are composed of more densely packed maculae, causing them to appear as vertical, darker streaks in some areas of vertical sections; galleries oval, some superposed to form pseudozooidal tubes, average 0.11 mm in height, 0.12 mm in breadth; astrorhizal tubes well developed, larger than galleries, average 0.14 mm in height, 0.16 mm in breadth, astrorhizae superposed; dissepiments are rare, a few in astrorhizal tubes, none in pseudozooidal tubes; one to five pseudozooidal tubes in 2 mm; thin basal perithecium of dark, compact tissue present.

Tangential section.—Tissue coarsely maculate; pillars large, round, coalescent, 0.12 to 0.28 mm in diameter, averaging 0.17 mm; astrorhizae prominent, ringed by three or four annuli of laminae, with central tube and radiating, bifurcating canals, canals of adjacent astrorhizae join to form a network of anastomosing canals, overall diameter of astrorhizae 6.1 mm, 6.8 mm from center to center, width of canals from 0.14 to 0.21 mm; galleries round, vermicular, diameter 0.04 to 0.14 mm, averaging 0.08 mm; tissue covers about 70% of the area of the section.

Discussion.—Distinctive features of *Syringostroma astrorhizoides* are the alignment of the large maculae, both horizontally and vertically, in forming the laminae and pillars, the amalgamation of pillar and laminar tissue, the large round pillars, and the extensive development of astrorhizae for which the species is named. *S. astrorhizoides* is similar to *Stromatopora laminosa* Lecompte but has larger, better developed astrorhizae, more reticulate development of the maculae, and more definite pillars. It is similar to *Stromatopora*

divergens Galloway and St. Jean, but has coarser maculae, larger and more profuse astrorhizae, and frequent long pillars. The large round pillars seen in tangential section compare with those of *Syringostroma densum* Nicholson. The reticulate pattern of maculae resembles that of *Parallelopore*, but vertical tubules and rods are not present in the pillars.

Occurrence.—Abundant in the Callaway Formation at localities A and G; associated with crinoid columnals.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-79, 80. Cat. No. 3650; paratypes, slides 310-81, 82, 83. holotype in part, Univ. of Mo. Cat. No. 14722.

Genus **PARALLELOPORA** Bargatzky, 1881

Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 95, pl. 2, figs. 6, 7; Nicholson, 1891, vol. 44, p. 191; Parks, 1936, Univ. Toronto Studies, Geol. Ser., No. 39, p. 53; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, Bd. 2A, p. A45; Lecompte, 1952, Inst. Roy Sci. Nat. Belgique, Mém. 117, p. 292, pl. 51, figs. 3a-c; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F136; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 205; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 450, pl. 31, fig. 16; pl. 35, fig. 6; Galloway, 1960, Jour. Paleont., vol. 34, No. 4, p. 632.

Type species, *Parallelopore ostiolata* Bargatzky, 1881, Verhandl. naturhist. Vereins preuss. Rheinlandes Westfalens, vol. 38, p. 291 (Middle Devonian, Germany).

Coenosteum massive, latilaminar; laminae composed of microlaminae, subordinate to pillars; pillars separate or confluent, continuous or superposed, composed of vertical rows of maculae with dark, superposed maculae forming rods, with clear tubular spaces between rods; large astrorhizae present; dissepiments plentiful in some species.

Parallelopore dartingtonensis (Carter) Pl. 3, fig. 8; Pl. 14, figs. 2a, b, c

Stromatopora dartingtonensis Carter, 1880, Ann. Mag. Nat. Hist., ser. 5, vol. 6, p. 339, pl. 18, figs. 2-5 (Middle Devonian, Dartington, England).

Parallelopore dartingtonensis (Carter), Nicholson, 1891, Palaeontographical Soc., vol. 44, p. 199, pl. 24, figs. 13-15; pl. 25, figs. 1-3.

Coenosteum.—Large, dome-shaped masses; height of partial specimen 3 cm, diameter 11 cm; surface uneven, mamelons absent, papillate; astrorhizae well developed but entire astrorhiza rarely observable, with long, branching canals, some to 10.0 mm in length,

spacing sporadic, superposed as seen in polished vertical section; latilaminae thick, averaging 3 to 5 mm, two in 1 cm, composed of wide, light bands of laminae and narrower, dark bands.

Vertical section.—Tissue does not appear as maculate as typical species of the genus, but tissue of both pillars and laminae coarsely tubulate in vertical direction, tubules probably spaces between rods of superposed maculae, pillar and laminar tissue confluent; laminae irregular, not continuous, difficult to distinguish because lumen-like tubules run through laminae and pillars alike, thickness varies from 0.08 to 0.18 mm but never the same thickness for any distance, five or six laminae in 2 mm; pillars both short and long, of same tissue as laminae, contain one or more coarse tubules 0.02 mm in diameter, pillars 0.08 to 0.28 mm thick, averaging 0.14 mm., six or seven in 2 mm; galleries irregularly shaped, bordered by one or more dissepiments and sometimes divided by dissepiments, height 0.08 to 0.34 mm, averaging 0.25 mm, breadth 0.12 to 0.70 mm, averaging 0.30 mm; many galleries superposed, separated by dissepiments, forming pseudozooidal tubes, two to five in 2 mm; large astrorhizal tubes with branching canals present, axial tube about 0.09 mm in diameter present with dissepiments which resemble tabulae, branching canals from 0.20 to 0.53 mm in diameter; dissepiments numerous in galleries, astrorhizal tubes and canals, generally are convex upward, connect pillars, form a base in some instances for growth of pillar and laminar tissue.

Tangential section.—Tissue appears maculate, cross sections of vertical tubules give appearance of coarse maculae; galleries circular, vermicular, irregular in shape; astrorhizae large, 6 to 9 mm in overall diameter, bifurcating canals radiate from central tube, central tube averages 0.60 mm in diameter, radiating canals from 0.11 to 0.52 mm wide; pillars round, coalescent, some round pillars with one or more lumina, some join in such fashion to make rings, average 0.14 mm in diameter; gallery space and tissue each occupy 50% of the section.

Discussion.—Distinctive features of the Missouri specimens of *Parallelopore dartingtonensis* (Carter) are the large astrorhizae, conspicuous development of dissepiments, and tubules in vaguely maculate tissue.

Occurrence.—Common in the Callaway Formation at locality

H; overgrown with *Trupetostroma kennissoni* Birkhead, n. sp. and associated with *Stachyodes spongiosum* Stearn; limestone is light gray, crystalline, and fossiliferous.

Hypotypes.—North Carolina University Paleontological Collections, slides 310-84, 85, 86. Cat. No. 3648.

Parallelopora catenaria Birkhead, n. sp. Pl. 4, fig. 2; Pl. 14, figs. 3a, b, c

Coenosteum.—Irregular laminar masses; height of specimens collected 1.0 to 15.0 mm, fragmental specimen 13.0 cm in diameter; surface undulatory, mamelons and astrorhizae indefinite, peritheca not observed; latilaminae of thick light bands and narrower dark bands, light bands average 1.5 mm thickness, dark bands about 0.50 mm thickness, four to seven latilaminae in 1 cm; entire thickness of a coenosteum not observed, because only fragments were seen along with other organic debris in the limestone.

Vertical section.—Tissue coarsely maculate; laminae thin, poorly defined, 0.04 to 0.06 mm thick, averaging 0.05 mm, seven to nine in 2 mm; pillars long, appear short and irregular where section is oblique, large darker maculae at centers of some pillars, pillars 0.70 to 3.00 mm long, average 0.28 mm width, four to six in 2 mm, composed of superposed maculae; galleries round to subrectangular, 0.07 to 0.64 mm broad, averaging 0.25 mm, 0.14 to 0.58 mm high, averaging 0.21 mm, some galleries superposed to form pseudozooidal tubes, pseudozooidal tubes long and short, some branching, microlaminae crossing tubes give tabular appearance, four pseudozooidal tubes in 2 mm; dissepiments rare; no mamelon structures seen in vertical section.

Tangential section.—Tissue coarsely maculate, large maculae, 0.03 to 0.07 mm diameter occur sporadically in pillar tissue, a thin band of compact tissue of uniform denseness borders galleries; pillars coalescent, form chainlike network, 0.06 to 0.15 mm in diameter, averaging 0.11 mm; galleries oval, vermicular; astrorhizae vague, occur sporadically, with central tube and short, radiating canals, only segments of canals visible, average diameter of tubes and canals 0.26 mm, overall diameter of astrorhizae about 0.47 cm.

Discussion.—Distinctive features of *Parallelopora catenaria* are the coarse maculae of the tissue, some which occur near centers of the pillars are dark and surrounded by maculae of lighter brown

color; the thin band of compact tissue lining the galleries; and the pseudozooidal tubes transected by microlaminae. The species is similar to *Parallelopora ostiolata* Bargatzky, but astrorhizae are not so well developed as in that species, pillars are broader, maculae of tissue are generally larger, and laminae do not have as much cystlike appearance.

Occurrence.—Common in the Callaway Formation at locality A. *Parallelopora catenaria* occurs with *Favosites* sp. and crinoid debris, none of which is in place. The enclosing sediment is argillaceous limestone which contains many fossil fragments.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-87, 88. Cat. No. 3649; paratype, slide 310-89.

Genus **HERMATOSTROMA** Nicholson, 1886

Nicholson, 1892, Palaeontographical Soc., vol. 46, p. 215, pl. 28, figs. 12, 13; Ripper, 1937, Roy. Soc. Victoria, Proc., vol. 50, pt. 1, new ser., p. 29; Lecompte, 1952, Inst. Roy. Sci. Nat. Belgique, Mém. 117, p. 247; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F131; Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst., Minister. Geol. i Ochrany Nedr. nov. ser., vol. 8, pp. 140-149, pls. 72, 76-79; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 218, pl. 21, figs. 1a, b; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 451, pl. 35, fig. 7.

Type species (monotypic), *Hermatostroma schlüteri* Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 105, pl. 3, figs. 1, 2 (Middle Devonian, Hebborn, Germany).

Coenosteum massive; tissue coarsely maculate; pillars and laminae well developed; pillars long and short; margins of pillars and laminae are lighter in color and coarsely maculate or bound by clear sheaths; with or without astrorhizae; latilaminae present; mamelons present or absent; pseudozooidal tubes may be present but not commonly developed.

Hermatostroma insulata Birkhead, n. sp. Pl. 15, figs. 1a, b, c, d

Coenosteum.—Large, massive, average specimen 13.0 cm high, 11.5 cm wide, and 9.0 cm in depth; surface knobby, with mamelons 2 to 4 mm in diameter and 1 to 3 mm high, spaced 5 to 10 mm apart, center to center; astrorhizae indistinct on surface of coenosteum; latilaminae 2 to 7 mm thick, two to six in 1 cm.

Vertical section.—Tissue coarsely maculate, maculae 0.04 to 0.12 mm in diameter, averaging 0.08 mm; laminae variable in thickness, some laminae are planes of maculae one macula thick,

laminae regular, some with light median layer of tissue, laminae 0.07 to 0.35 mm thick, averaging 0.30 mm, nine in 2 mm; pillars slightly more prominent than laminae, sheathed in vesiculate tissue, average pillar thickness 0.11 mm, nine occurring in 2 mm, pillars in mamelons not different from other pillars; galleries round, oval, superposed in some places; dissepiments present in some galleries; astrorhizal tubes with dissepiments and branching canals present, tubes superposed in mamelon columns; latilaminae present, due to difference in thickness of laminae and interlaminar spaces.

Tangential section.—Tissue coarsely maculate; pillars mostly coalescing to form chainlike groups, average 0.15 mm in diameter, adjacent pillars share maculae, pillars may be surrounded by large, clear-centered vesicles; astrorhizae with long, branching canals and circular central tube, tubes and canals with few dissepiments, vary in diameter from 0.10 to 0.40 mm, averaging 0.30 mm; galleries circular, vermicular; about 60% of section is tissue and 40% is gallery space.

Discussion.—*Hermatostroma insulata* is similar to *Hermatostroma logansportense* Galloway and St. Jean but differs in having superposed astrorhizae, regular laminae, a knobby coenosteum, and some dissepiments, especially in the astrorhizal tubes. The species differs from *Hermatostroma schlüteri* Nicholson in having astrorhizae, and vesicular rather than clear sheaths around the pillars. *H. insulata* is similar to some species of *Taleastroma* but has the light-colored borders of pillars and vesiculate tissue.

The vesicular sheaths, to which the trivial name refers, are prominent in parts of a vertical section but less noticeable in other parts. There is also a variance in the appearance of the laminae which is due to differing thicknesses of the laminae.

Occurrence.—Abundant in the Callaway Formation at locality M.

Types.—Holotype, North Carolina University Paleontological Collections, slides 310-92, 95, 96, Cat. No. 3652; paratypes, slides 310-93, 94; holotype in part, Univ. of Mo. Cat. No. 14733.

Genus **CLATHROCOILONA** Yavorsky, 1931

Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst., Minister. Geol. i Ochrany Nedr. nov. ser., vol. 8 pp. 38, 39, pl. 13, figs 1-7; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 222,

pl. 21, figs. 3a, b; pl. 23, figs. 1a, b; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 451, pl. 35, fig. 8.
Stromatoporella (part) Lecompte, 1951, Inst. Roy. Sci. Nat. Belgique, Mém. 116, p. 152; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F131.

Type species (monotypic), *Clathrocoilona abeona* Yavorsky, 1931, Bull. United Geol. and Prosp. Service, U.S.S.R., vol. 50, fasc. 94, p. 1407, pl. 1, figs. 9-11; pl. 2, figs. 1, 2, 2a (Middle Devonian, S.W. border Kuznetsk Basin, Russia).

Coenosteum lamellar to massive, many species encrusting; laminae tripartite in some species, with light median layer of tissue; tissue maculate, tubulate; pillars mostly short, spool-shaped; galleries round or oval; dissepiments present in astrorhizal canals; astrorhizae and mamelons commonly present; latilaminar.

Clathrocoilona subclathrata Galloway and St. Jean Pl. 16, figs. 1a, b

Clathrocoilona subclathrata Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 224, pl. 21, figs. 4a, b.

Coenosteum.—Massive, sometimes flat, laminar; height 0.50 mm to 2.20 cm, diameter of part of a coenosteum 15 cm; surface irregular, with low mamelons 1 to 2 mm in diameter, 0.50 to 1.00 mm high, about 3 mm from center to center; astrorhizae present, with central tube from which extend canals, overall diameter of astrorhizae 3.0 mm, about 3.5 mm from center to center; latilaminae consist of three to five regular laminae, 1.0 mm thick, eight or nine in 1 cm.

Vertical section.—Tissue maculate, but in places appears compact with a network of tubules; part of laminae tripartite, with clear median layer of tissue, laminae bend gently and abruptly into mamelons, 0.09 to 0.21 mm thick, averaging 0.17 mm, eight in 2 mm; astrorhizal canals oval, elongate between the basal and second laminae of each latilamina, some superposed, connected by foramina; galleries 0.09 to 0.23 mm high, 0.09 to 0.70 mm broad, averaging 0.18 mm in height and breadth, some superposed to form pseudozooidal tubes; none to three pseudozooidal tubes in 2 mm; pillars short, spool-shaped, confined between two laminae, some superposed, five to eight in 2 mm, diverge slightly in mamelons; latilaminae composed of three to five laminae, basal lamina of each latilamina consists of denser, more compact tissue than that of other laminae and has a more definite clear, median layer of tissue;

dissepiments occur mostly in astrorhizal canals but also in some galleries.

Tangential section.—Tissue has flocculent, maculate appearance, tubules or small canals present through the tissue; pillars round between laminae, some elongate, vermicular, 0.07 to 0.24 mm in diameter, averaging 0.13 mm, 0.12 mm apart between borders; galleries anastomose; segments of astrorhizae present, canals irregularly radiating, some from central tube, generally only portions of astrorhizae present, canals small, 0.12 to 0.25 mm in width, averaging 0.14 mm; dissepiments rare.

Discussion.—*Clathrocoilona subclathrata* Galloway and St. Jean is characterized by the tripartite laminae and dissepiments which occur in the astrorhizal tubes. Latilaminae are marked, in the Missouri specimens, by a basal row of oval and elongate astrorhizal tubes of larger size than the regular galleries, and each basal lamina of a latilamina is definitely tripartite and composed of denser tissue than the tissue of succeeding laminae. The coenostea grow three or four laminae, whereupon a dense layer of tissue is deposited and three or four more laminae are added. This process is repeated throughout the thickness of the Missouri specimens. Coenostea grew around *Stachyodes crebrum* Stearn, brachiopods, corals, or any object which was in the path of growth or which fell upon the coenosteum while growth was in progress. The direction of growth was laterally after a vertical build-up of three or four laminae. The coenostea found in Missouri have fewer dissepiments, and the laminae are more closely spaced than in the specimens described from the Logansport Limestone of Indiana. Those from Indiana show more features in vertical section because of their massive habit of growth instead of repeated overgrowth of flat coenostea as in the Missouri specimens.

Occurrence.—Abundant in the Callaway Formation at localities G and M; rare in the Snyder Creek Formation at locality K, where the species is associated with *Stromatoporella foraminosa* Birkhead, n. sp.

Hypotypes.—North Carolina University Paleontological Collections, slides 310-97, 100, 311-01, 312-06. Cat. No. 3653; Univ. of Mo. Cat. No. 14732.

Genus **PSEUDOACTINODICTYON** Flügel, 1958

Type species, *Pseudocatinodictyon juxi* Flügel, 1958, *Senckenbergiana Lethaea*, Bd. 39, Nos. 3-4, p. 137 (Middle Devonian, Germany). Stearn, 1962, *Geol. Sur. Canada, Dept. Mines Tech. Sur., Bull.* 92, p. 17.

Coenosteum laminar, massive, or hemispherical; surface mame-late; pillars and laminae present, composed of confluent maculate tissue; dissepiments abundant, filling much of the galleries; astro-rhizae present; distinguished from *Actinodictyon* Parks by the presence of laminae.

Pseudoactinodictyon mineolaensis Birkhead, n. sp. Pl. 15, figs. 2a, b, c, d

Coenosteum.—Low hemispherical, wafer-shaped; height 2 cm, diameter 6 cm; surface weathered irregularly; mamelons obscure; papillae present; astrorhizal structures vague, can be detected on unweathered surfaces of the coenosteum, consist of grooves radiat-ing from a central point, overall diameter about 5 mm, occur sporadically; latilaminae absent.

Vertical section.—Tissue maculate, with small, well-defined maculae composed of dark borders and clear centers which pro-duces a fine frothy appearance; laminae indistinct, difficult to trace in some areas of section, microlaminae present but thin and irregular; pillar and laminar tissue confluent; skeleton composed of a framework of dissepiments of dense tissue with light, flocculent, maculate tissue filling gallery spaces between dissepiments in many places; dissepiments 0.02 mm thick; galleries oval, irregular, 0.13 to 0.40 mm broad, averaging 0.20 mm, 0.06 to 0.20 mm high, aver-aging 0.16 mm, some galleries superposed, separated by dissepi-ments, form pseudozoooidal tubes, about three in 2 mm; astrorhizal columns developed with laminae turning gently upward into them, tubes frequent in astrorhizal columns, with dissepiments which give more numerous development of pseudozoooidal tubes in the columns.

Tangential section.—Tissue finely maculate; pillars coalescent, anastomosing, average 0.16 mm in diameter; galleries oval, elon-gate, irregular in shape, averaging 0.20 mm in diameter; astro-rhizae conspicuous, with two or three central tubes and branching, radiating canals, canals interconnect between adjacent astrorhizae,

central tubes average 0.20 mm in diameter, radiating canals same diameter as central tubes, segments of canals scattered over section, dissepiments in all canals and tubes; 60% of area of section is tissue and 40% is gallery space.

Discussion.—Distinctive characteristics of *Pseudoactinodictyon mineolaensis* are the maculate tissue built into a framework of dissepiments, extensive development of dissepiments, and the large astrorhizae with wide canals. The species is similar to *Pseudoactinodictyon vagans* (Parks) but has a more definite astrorhizal system. It is also comparable to *Pseudoactinodictyon norrisi* Stearn but does not have as regular development of pillars and laminae as that species.

Occurrence.—Rare in the Callaway Formation at locality G, Mineola facies (to which the trivial name refers).

Holotype.—North Carolina University Paleontological Collections, slides 311-05, 06. Cat. No. 3654.

Family **IDIOSTROMATIDAE** Nicholson, 1886

Family Idiostromidae Nicholson, 1886, Palaeontographical Soc., vol. 39, pp. 74, 98.

Familia Idiostromatidae Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, p. A52.

Coenosteum cylindrical, dendroid, or fasciculate; erect branches, some with branched or unbranched axial tube which may or may not contain dissepiments; skeleton composed of transversely fibrous or porous tissue, not maculate; laminae thick; pillars regular to irregular, short; astrorhizae absent.

Genus **AMPHIPORA** Schulz, 1883

Amphipora Schulz, 1883, Jahrb. Königl. Preuss. geol. Landesanstalt, for 1882, p. 245, pl. 22, figs. 5, 6; pl. 23, fig. 1; Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 109, pl. 9, figs. 1-4; Nicholson, 1892, vol. 46, p. 223, pl. 29, figs. 3-7; Felix, 1905, Stützungsber. Naturforsch. Gesell. Leipzig, for 1903-1904, vols. 30, 31, pp. 73-75, 2 figs.; Yabe and Sugiyama, 1933, Japanese Jour. Geol. Geog., vol. 11, p. 19; Ripper, 1937, Roy. Soc. Western Australia Jour., vol. 23, p. 37; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, p. A54; Sugiyama, 1942, Geol. Soc. Japan Jour., vol. 49, p. 112; Lecompte, 1952, Inst. Roy. Sci. Nat. Belgique, Mém. 117, p. 321; Yavorsky, 1955, Trudy Vsesoyuznogo Nauchno-issledovatel'skogo Geol. Inst. Minister. Geol. i ochrany Nedr. nov. ser., vol. 8, pp. 149-154, pls. 80-84; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F142; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 232; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 442, pl. 31, fig. 13; pl. 34, fig. 7; Stearn, 1963, Jour. Paleont., vol. 37, No. 3, p. 662.

Type species (monotypic), *Caunapora ramosa* Phillips, 1841, Figures and descriptions of the Palaeozoic Fossils Cornwall, Devon, and West Somerset, p. 19, pl. 8, fig. 22 (Middle Devonian, South Devon, England).

Coenosteum slender, ramose, branching, occurs singly or in coquina-like masses; axial canal large, small, or sometimes absent; skeleton composed of anastomosing galleries and pillars; tissue transversely fibrous with dark median line in laminae and pillars.

***Amphipora ramosa* (Phillips)**

Pl. 16, figs. 2a, b

Caunopora ramosa Phillips, 1841, Figures and descriptions of the Paleozoic fossils of Cornwall, Devon and West Somerset . . . p. 19, pl. 8, figs. 22a-c (Middle Devonian, England).

Stromatopora (Caunopora) ramosa Phillips, McCoy, 1851, A Systematic Description of the British Paleozoic Fossils in the Geological Museum of the University of Cambridge, vol. 1, p. 67.

Amphipora ramosa Phillips, Schulz, 1883, Jahrb. Konigl. Preuss. geol. Landesanstalt Bergakad., Abhandl., for 1882, p. 245, pl. 22, figs. 5-7; pl. 23, fig. 1 (Middle Devonian, Germany); Nicholson, 1886, Paleontographical Soc., vol. 39, p. 109, pl. 9, figs. 1-4 (Middle Devonian, Germany); Nicholson, 1892, vol. 46, p. 223, pl. 29, figs. 3-7 (Middle Devonian, England); Gürich, 1896, Verh. Russ. Kais. Mineralog. Gesell., vol. 32, p. 129, pl. 1, fig. 5; Felix, 1905, Sitzungsber. Naturf. Gesell., vols. 30, 31, p. 74, text figs. 1-3; Vinassa de Regny, 1910, Boll. R. Com. Geol. Italia, vol. 41, p. 48, pl. 1, figs. 9, 10; Heinrich, 1914, Inaugural Dissertation, Friedrich-Wilhelms Universitat, Bonn., p. 46; Vinassa de Regny, 1918, Paleontographica Italica, vol. 24, p. 109, pl. 9 (4), figs. 14, 15 (Middle Devonian, Italy); Riabinin, 1931, Bull. Geol. Prosp. Serv. U.S.S.R., vol. 31, p. 508, pl. 1, figs. 11-13 (Middle Devonian, Russia); Le Maître, 1934, Soc. Geol. Nord, Mém., vol. 12, p. 202, pl. 17, figs. 2-4 (Middle Devonian, France); Öpik, 1935, Ann. Nat. Soc. Tartu Univ., Pub. Geol. Inst. No. 41, p. 3, text fig. 1, pls. 1, 2 (Middle Devonian, Estonia); Le Maître, 1937, Bull. Soc. Géol. France, ser. 5, vol. 7, p. 121, pl. 8, figs. 4, 5; pl. 9, fig. 6; Ripper, 1937, Roy. Soc. Western Australia, Jour., vol. 23, p. 38, text figs. 1-3, pl. 1 (Middle Devonian, Western Australia); Schäfer, 1938, Austria Geol. Bundesanst. Verh., Nos. 3, 4, p. 114, text figs.; Kühn, 1939, in Schindewolf, Handbuch Paläozoologie, Bd. 2A, p. A54, text fig. 85; Sugiyama, 1942, Geol. Soc. Japan, Jour., vol. 49, No. 587, p. 112, pls. 4 (3); 5 (4); Lecompte, 1952, Inst. Roy. Sci. Nat. Belgique, Mém. 117, p. 325, pl. 67, fig. 3; pl. 68; figs. 1-7 (Middle Devonian, Belgium); Yavorsky, 1955, Stromatoporoidea Sovetskogo Soyuza, vol. 8, p. 152, pl. 82, figs. 1-6; 1957, *ibid.*, vol. 18, p. 63, pl. 41, figs. 1-9; 1961, *ibid.*, vol. 44, p. 58, pl. 36, fig. 15; pl. 37, figs. 1-10; 1963, *ibid.*, vol. 87, p. 84, pl. 31, figs. 1-6; Galloway and St. Jean, 1957, Bull. Amer. Paleont., vol. 37, No. 162, p. 233, pl. 23, figs. 2-6 (Middle Devonian, United States); Stearn, 1961, Jour. Paleont., vol. 35, No. 5, p. 946, pl. 107, figs. 9, 10; Stearn, 1963, Jour. Paleont., vol. 37, No. 3, p. 663, pl. 87, fig. 2.

Coenosteum.—Small, ramose, 1 to 4 mm in diameter and maximum of 2.5 cm in length; forms beds of wide areal extent; surface covered with anastomosing ridges and grooves; mamelons and astrorhizae absent; some coenostea branching.

Cross section.—Tissue fibrous; laminae and pillars confluent, with dark, thick, median line; axial tube may or may not be present, if present averages 0.20 mm in diameter, but reaches 0.66 mm in some specimens; galleries more prominent near surface, oval, 0.10 to 0.60 mm broad, connected to each other and to axial tube; dissepiments rare; gallery spaces diminished in cross sections which have small axial tube or none at all; cross sections of specimens with a large axial tube have increased gallery space, the tissue of laminae and pillars forming an open network; tissue of the more open forms greatly resembles the fibrous tissue of the pillars in some of the species of the genus *Anostylostroma*.

Axial section.—Laminae vague, but appear to be formed in concentric layers around the axial tube in some sections; pillars average 0.13 mm in thickness, irregular, anastomosing; axial tube single, averaging 0.20 mm in diameter but some of larger variety reach 0.60 mm, dissepiments crossing axial tube rare; most gallery space seen around periphery, galleries oval to elongate, averaging 0.13 mm breadth; pillars and laminae become more regular near perimeter of section.

Tangential section.—Pillars anastomose, confluent with laminae, galleries oval, vermicular, connected; dark, median line present in pillar and laminar tissue; sections average about 70% tissue and 30% gallery space.

Discussion.—Small, ramose coenostea with or without axial tubes which are variable in diameter, mostly irregular pillars and laminae of fibrous tissue with black median line, and absence of astrorhizae and mamelons are features characteristic of *Amphipora ramosa* (Phillips).

Occurrence.—Very abundant in the Callaway Formation at localities A and G; found in beds up to one and one-half feet thick and also found as scattered coenostea; associations include *Stachyodes crebrum* Stearn, *Stachyodes spongiosum* Stern, and *Favosites* sp.; may have been inhabitants of back reef and platform areas.

Hypotypes.—North Carolina University Paleontological Collections, slides 311-09, 13. Cat. No. 3655.

Genus **STACHYODES** Bargatzky, 1881

Nicholson, 1886, Palaeontographical Soc., vol. 39, p. 107, pl. 8, figs. 9-14; pl. 11, fig. 5; Nicholson, 1892, vol. 46, p. 221, pl. 29, figs. 1, 2; Kühn, 1939,

in Schindewolf, Handbuch Paläozoologie, p. A52; 1942, Zool. Anz., Leipzig, vol. 140, p. 250; Lecompte, 1952, Inst. Roy. Sci. Nat. Belgique, Mém. 117, p. 298; Lecompte, 1956, in Moore, Treatise Invert. Paleont., Part F, p. F136; Galloway, 1957, Bull. Amer. Paleont., vol. 37, No. 164, p. 444, pl. 34, fig. 10; Yavorsky, 1957, Stromatoporoidea Sovetskogo Soyuz, vol. 18, pt. 2, p. 58; Stearn, 1962, Geol. Sur. Canada, Dept. Mines Tech. Sur., Bull. 92, p. 8; Stearn, 1963, Jour. Paleont., vol. 37, No. 3, p. 660.

Types species (monotypic), *Stachyodes verticillata* (McCoy) = *Stromatopora* (*Caunopora*) *verticillata* McCoy, 1851, British Palaeozoic Fossils, p. 66, text figs. a, b, = *Stachyodes ramosa* Bargatzky, 1881, Zeit. Deut. Geol. Gesell., vol. 33, p. 688 (Middle Devonian, Germany).

Coenostea interconnecting masses of branches or single branches scattered through limestone matrix; axial tube present, crossed by thin microlaminae which have appearance of tabulae; laminae of most of skeleton thick, with thin dark or light median line (the microlamina); pseudozooidal tubes present which radiate from and are perpendicular to axial canal, branch near surface of coenosteum; tissue compact but sometimes with tubules; pillars short, confined to one interlaminar space, generally indefinite; astrorhizae absent.

***Stachyodes crebrum* Stearn**

Pl. 16, figs. 3a, b

Stachyodes crebrum Stearn, 1962, Geol. Sur. Canada, Dept. Mines Tech. Sur., Bull. 92, p. 9, pl. 4, figs. 1-3, 5, 6.

Coenosteum.—Dendroid, occurs in masses of intertwining branches, of anastomosing nature, closely appressed, with or without fusion of branches; branches taper, diameter from 1.50 to 3.00 mm, length about 1.20 cm, size of entire mass indeterminate; coenosteal masses form network for accumulation of sediment and organic remains; surface of coenostea marked by anastomosing ridges and grooves; no mamelons, papillae, or astrorhizae present; some branches are attached to an irregular, flat base from which they appear to have grown.

Cross section.—Tissue compact but tubulate; axial region usually with more than one axial tube 0.10 to 0.50 mm in diameter; galleries present near periphery, oval in shape, average 0.10 mm in breadth, some connected, forming elongate vesicles; laminar and pillar tissue confluent, laminae and pillars indistinct, faint median clear line rarely seen in laminae.

Axial section.—Laminae highly arched, vague where clear line in laminae is not developed; tissue tubulate; segments of axial canals present, no dissepiments observed in canals; some coenostea sheathed in a layer of clear calcite as seen in axial section; galleries small, average 0.10 mm. in breadth, oval, some connected, sparse.

Tangential section.—Pillars anastomosing; galleries connected, irregular, anastomosing; tissue with tubules about 0.02 mm in diameter which sometimes give a granular appearance to the tissue; laminar and pillar tissue confluent; 60% of section is tissue, 40% gallery space.

Discussion.—The small coenostea, tubulate tissue, and multiple canals in the axial region are features of *Stachyodes crebrum* Stearn. The coenostea of the Missouri specimens are smaller than those described by Stearn (1962, p. 9). The species is similar to *Stachyodes verticillata* (McCoy), but coenostea are smaller, pillars are not so distinct, and canals in the axial area are more numerous.

Occurrence.—Abundant in the Callaway Formation at localities A, E, G, and H. A small brachiopod is commonly found among the branches of the coenostea of *Stachyodes crebrum*. A horn coral, *Cystiphyllum* sp., and colonial coral, *Favosites* sp., are also intermingled in the coenostea. The limestone matrix is argillaceous.

Hypotypes.—North Carolina University Paleontological Collections, slides 311-07, 08, 11. Cat. No. 3656.

***Stachyodes spongiosum* Stearn**

Pl. 16, figs. 4a, b

Stachyodes spongiosum Stearn, 1963, Jour. Paleont., vol. 37, No. 3, p. 661, pl. 86, figs. 6-8.

Coenosteum.—Ramosely, occurs in masses and as individual coenostea scattered through limestone; diameter of individual coenostea and isolated branches 1.60 to 6.00 mm, length up to 2.40 cm; diameter of massive beds indeterminate, but some beds cover square miles in association with *Amphipora ramosa* (Phillips); surface of branches marked by anastomosing ridges and grooves; no mamelons, astrorhizae, or papillae present.

Cross section.—Tissue compact; laminae and pillars indistinct except where median dark or clear line occurs in laminae; axial canal present, 0.10 to 0.73 mm in diameter, averaging 0.20 mm;

galleries few, oval in shape, average 0.13 mm in diameter; pillars confined to one interlaminar space where discernible, occupy most of interlaminar space; laminae average 0.13 mm in thickness where measurable, form concentric rings around axial tube.

Axial section.—Laminae highly arched; axial tube single, connected to galleries; microlaminae extend across axial tube; galleries oval, some connected, occupy small percentage of section area; axial section has same appearance as cross section except for longitudinal view of axial tube and high-arched laminae instead of laminae in concentric rings around axial tube.

Tangential section.—Pillars anastomosing; tissue occupies most of section; galleries small, oval, some vermicular; small round openings in tissue present, may be cross sections of tubules in tissue; about 80% of section is tissue, 20% open spaces.

Discussion.—The tissue and median line of the laminae of *Stachyodes spongiosum* Stearn are similar to the tissue and median line of the laminae found in some species of *Trupetostoma*, though laminar-pillar architecture is noticeably different. *S. spongiosum* has more gallery space than *Stachyodes costulata* Lecompte and has smaller coenostea than *Stachyodes verticillata* (McCoy). The coenostea of *S. spongiosum* are larger than those of *Stachyodes crebrum* Stearn and have a single axial canal, whereas *S. crebrum* has multiple canals in the axial region.

Occurrence.—Abundant in the Callaway Formation at localities A, E, G, and H; found with *Amphipora ramosa* (Phillips), a small alga, the coral *Favosites*, and fragments of other organisms.

Hypotypes.—North Carolina University Paleontological Collections, slides 311-10, 12, 14, 15. Cat. No. 3657.

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PLATES

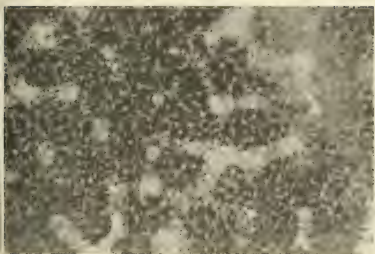
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EXPLANATION OF PLATE 3

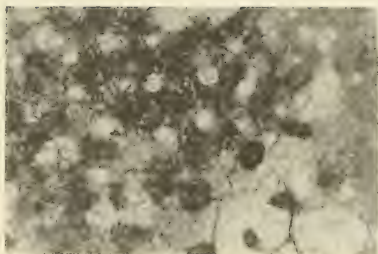
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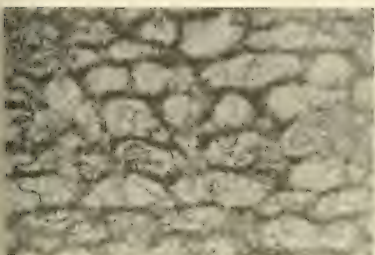
Figure		Page
1.	Syringostroma astrorhizoides Birkhead, n. sp. Tangential section demonstrating maculate tissue. Callaway Formation, locality A (slide 310-79). Holotype, No. 3650.	73
2.	Stromatoporella foraminosa Birkhead, n. sp. Tangential section showing vacuoles (small openings) and foramina (large openings) in tissue. Snyder Creek Shale, locality K (slide 310-31). Holotype, No. 3628.	51
3.	Clathrodictyon incongruum Birkhead, n. sp. Vertical section with finely fibrous, dusty tissue. Cyrene Member, Edgewood Formation of southeastern Missouri, locality F (slide 310-09). Holotype, No. 3623.	36
4.	Anostylostroma callawayensis Birkhead, n. sp. Vertical section illustrating coarsely fibrous tissue. Callaway Formation, locality A (slide 310-20). Holotype, No. 3629.	42
5.	Stromatoporella indubia Birkhead, n. sp. Tangential section showing anastomosing tubules in tissue in center of a lamina. Tubules are somewhat vague in the figure but are seen as light lines which form a network against the dark-tissue background. Some tubules appear to end in circular clear spots, which are actually cross sections of bending tubules. In other areas on the section, near upper or lower portions of laminae, tubules appear as simple, circular cross sections (see Pl. 10, figs. 1b, 1d). Callaway Formation, locality A (slide 310-46). Holotype, No. 3637.	56
6.	Trupetostroma ideale Birkhead, n. sp. Vertical section illustrating compact tissue. Callaway Formation, locality M (slide 310-53). Holotype, No. 3640.	60
7.	Stromatoporella ozoraensis Birkhead, n. sp. a. Vertical section (X25) showing structure of ring-pillars; left side of figure occupied by superposed ring-pillars formed by upturns of the laminae. b. Ring-pillars as they appear in tangential section (X25). Grand Tower Formation, locality O (slides 310-50, 49). Holotype, No. 3638.	57
8.	Parallelopore dartingtonensis (Carter) Vertical section demonstrating dissepiments in pseudozooidal tubes. Callaway Formation, locality H (slide 310-84). Hypotype, No. 3648.	75



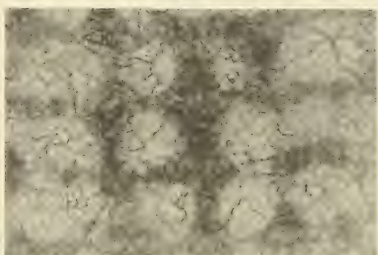
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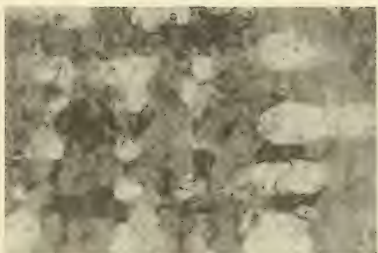
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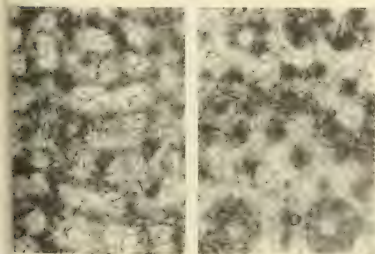
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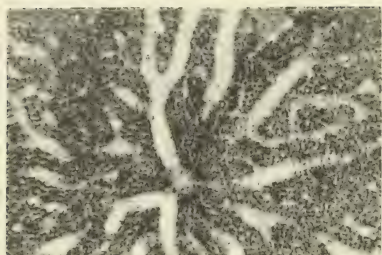


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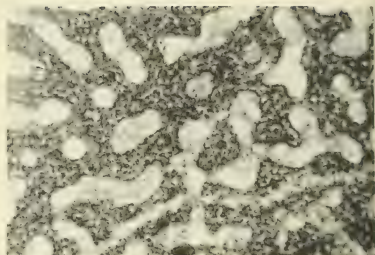
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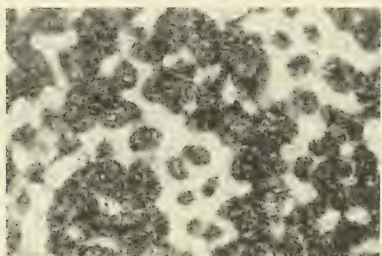
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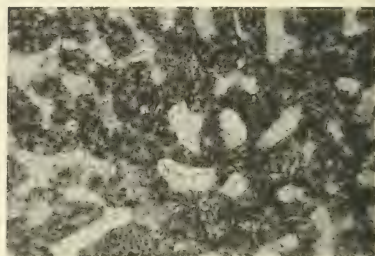
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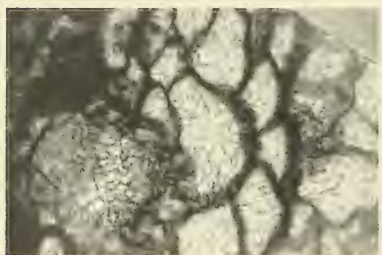
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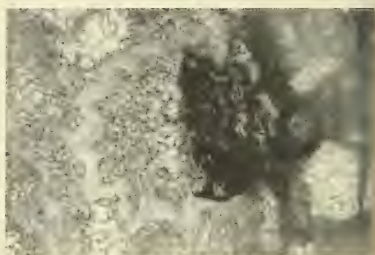
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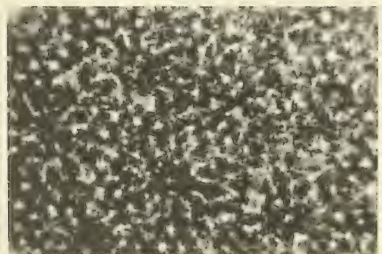
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5a



5b

EXPLANATION OF PLATE 4

Some Detailed Stromatoporoid Structures and Corals Which Resemble
Stromatoporoids in Thin Section

Figures 1, 2, 3a, and 3b are times 25. Figures 4a, 4b, 5a, and 5b are times 15.

Figure	Page
1. Syringostroma astrorhizoides Birkhead, n. sp.	73
Tangential section demonstrating detail of an astrorhiza; central tube with radiating, branching canals. Callaway Formation, locality A (slide 310-79). Holotype, No. 3650.	
2. Parallelopora catenaria Birkhead, n. sp.	77
Tangential section illustrating large maculae, coalescent pillars with compact outer sheath of tissue, and oval and vermicular galleries. Callaway Formation, locality A (slide 310-87). Holotype, No. 3649.	
3. Stromatoporella indubia Birkhead, n. sp.	56
a. Tangential section showing granulose tissue and lumina in some of the pillars. b. Tangential section showing multiple central tubes of astrorhizae and short, thick, segments of astrorhizal canals. Callaway Formation, locality A (slide 310-46). Holotype, No. 3637.	
4. Lyellia sp.	26
a. Illustration of dissepiments which resemble cyst plates of the stromatoporoid genera <i>Stromatocerium</i> and <i>Labechia</i> . b. Cross section of corallite of <i>Lyellia</i> which identifies the fossil as being other than stromatoporoid. Cyrene Member, Edgewood Formation, locality F (slide 311-24).	
5. Heliolites sp.	26
a. Tangential section of corallum in which coenenchymal tubules resemble pillars of some species of stromatoporoids. Outlines of corallites are vague, since radial septae blend with coenenchymal tubules, both features resembling galleries of stromatoporoids. b. Vertical section of corallum in which walls of coenenchymal tubules resemble pillars of <i>Labechia</i> and <i>Stromatocerium</i> . Cyrene Member, Edgewood Formation, locality F (slides 311-25, 312-08).	

EXPLANATION OF PLATE 5

Cryptozoön Sp.

All sections photographed for Plate 5 were compared with sections of topotypes of *Cryptozoön proliferum* Hall from the Upper Cambrian Hoyt Limestone, Saratoga Springs, New York, and found to be similar to them. The structures of the specimens from the Ordovician of Missouri were finer (not so coarse) than those of the topotypes. The structure of these stromatolites appears to be interconnected masses of tubes permeating the sediment. Tangential and vertical sections have much the same appearance and cannot be distinguished from one another unless sediment laminations are present in vertical section. All figures are times 10.

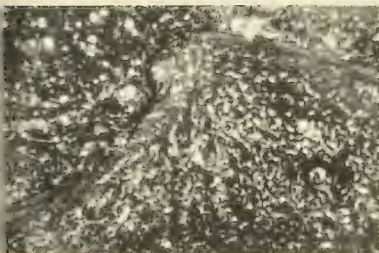
Figure	Page
1. Cryptozoön sp.	25
a. Vertical section; darker sediment lines give laminar appearance to section. b. Tangential section. Jefferson City Formation (Ordovician, Canadian Series), locality A (slides 311-16, 311-17).	
2. Cryptozoön sp.	25
a. Vertical section through mamelon-like structure. b. Tangential section. Jefferson City Formation, locality A (slides 311-18, 311-19).	
3. Cryptozoön sp.	25
a. Vertical section; darker sediment lines give latilaminar appearance to section. b. Tangential section which has same appearance as vertical section. Joachim Formation (Ordovician, Chazyan Age), locality D (slides 311-20, 311-21).	
4. Cryptozoön sp.	25
Figures a and b were made from a specimen taken from the Joachim Formation at an horizon 6 feet above the specimen from which the sections of figures 3a and b were made. The microscopic structure of the stromatolites from both horizons is the same. (Slides 311-22, 311-23).	



1a



1b



2a



2b



3a



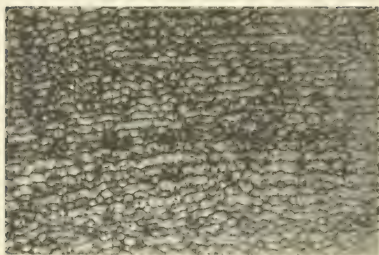
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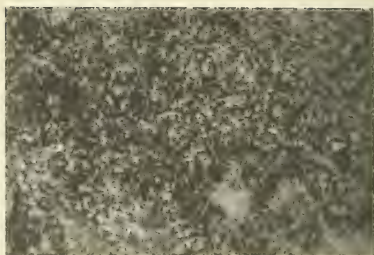
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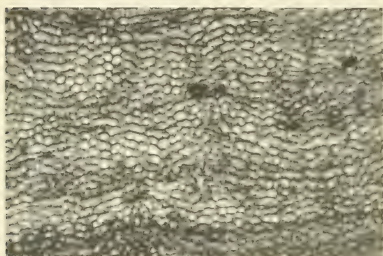
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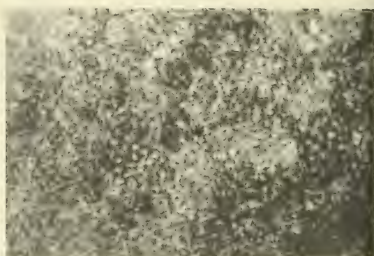
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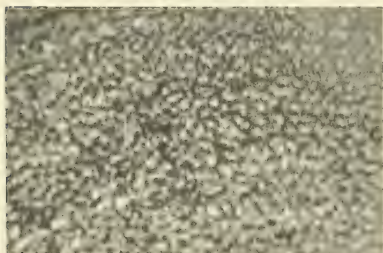
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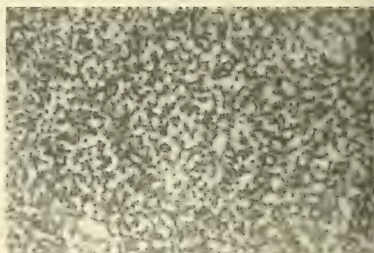
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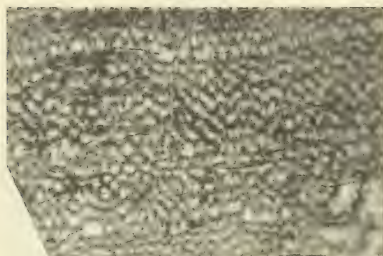
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4a



4b

EXPLANATION OF PLATE 6

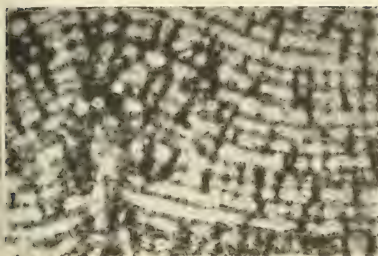
All figures are times 10.

Figure		Page
1.	Clathrodictyon incongruum Birkhead, n. sp.	36
	a. Vertical section; cyst plates arranged end to end, forming irregular laminae in lower one-third of section, regular in upper two-thirds.	
	b. Tangential section showing small, round pillars and anastomosing galleries; vague astrorhizal structure can be seen in right center of figure. Cyrene Member, Edgewood Formation of southeastern Missouri, locality F (slides 310-09, 310-10). Holotype, No. 3623.	
2.	Clathrodictyon mamillatum Birkhead, n. sp.	37
	a. Vertical section showing oval cysts arranged in undulatory laminae and upturned into mamillar columns. b. Tangential section showing round pillars; locations of mamillae marked by clusters of circular rings of tissue (just left of center of figure). Sexton Creek Formation of southeastern Missouri, locality L (slides 310-16, 310-17). Holotype, No. 3624.	
3.	Clathrodictyon cyrenensis Birkhead, n. sp.	38
	a. Vertical section showing cyst plates of thick tissue forming irregular laminae which are roughly zigzag in places. b. Tangential section showing small round pillars connected by cyst plate tissue, giving an irregular network appearance to the section; a vague astrorhizal structure is present just to the right of center of the section. Cyrene Member, Edgewood Formation, northeastern Missouri, locality I (slides 310-15, 310-14). Holotype, No. 3625.	
4.	Clathrodictyon maculosum Birkhead, n. sp.	39
	a. Vertical section showing thick tissue of cyst plates, zigzag arrangement of laminae, and part of superposed astrorhizae in lower right hand corner of the figure. b. Tangential section showing round and vermicular pillars, thick tissue, and astrorhiza. Cyrene Member, Edgewood Formation, northeastern Missouri, locality I (slides 310-12, 310-13). Holotype, No. 3626.	

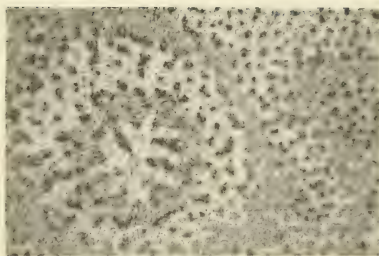
EXPLANATION OF PLATE 7

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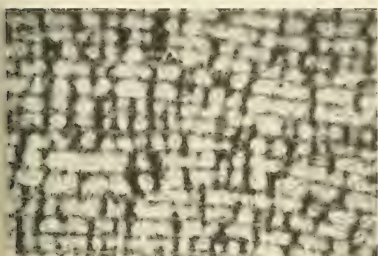
Figure	Page
1. Anostylostroma callawayensis Birkhead, n. sp.	42
a. Vertical section through astrorhizal tube and canals. b. Tangential section showing dark, round pillars and more elongate pillars in areas of mamelons; astrorhiza, occupying the mamelon area, has short, branching canals. c. Vertical section showing dark, coarsely fibrous pillars, which are short but superposed; laminae are lighter in color than pillars. Callaway Formation, locality A (slides 310-19, 310-20). Holotype, No. 3629.	
2. Anostylostroma bifurcacolumnare Birkhead, n. sp.	41
a. Tangential section; mamelon in lower left corner of section; ring-like pillars present within mamelon. b. Vertical section showing thick pillars and thin laminae. c. Vertical section through mamelon column showing the more closely spaced, thicker, and longer pillars of the mamelons. Callaway Formation, locality B (slides 310-18, 312-02). Holotype, No. 3627.	
3. Anostylostroma vermiculosum Birkhead, n. sp.	45
a. Vertical section; pillars short, thick; laminae of light-colored tissue, not regularly spaced. b. Tangential section showing thick, dark, vermicular-shaped pillars and lighter bands of laminar tissue. Callaway Formation, locality G (slides 310-30, 310-29). Holotype, No. 3632.	



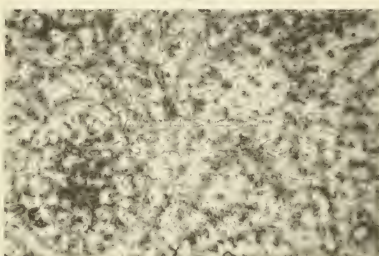
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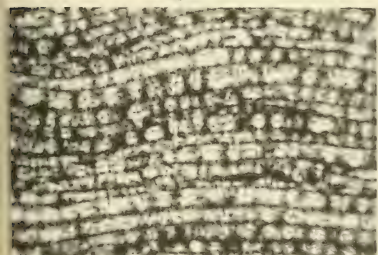
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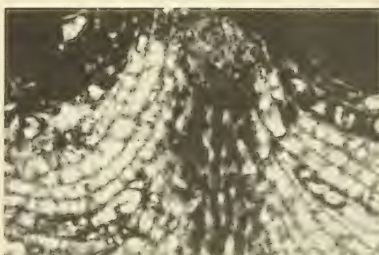
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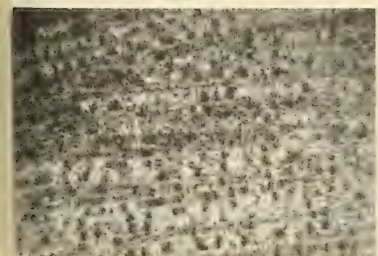
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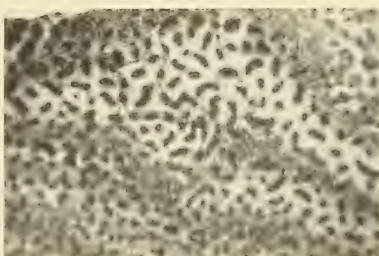
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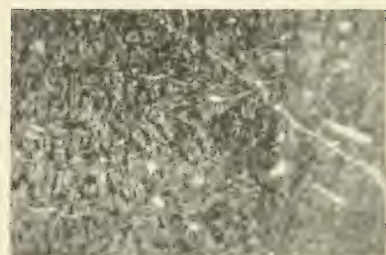
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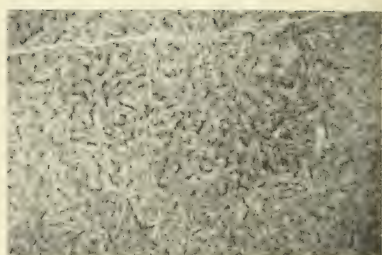
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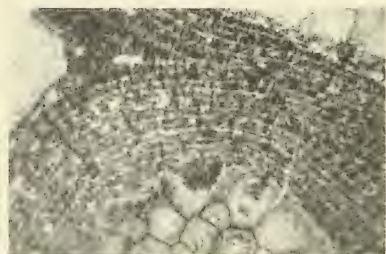
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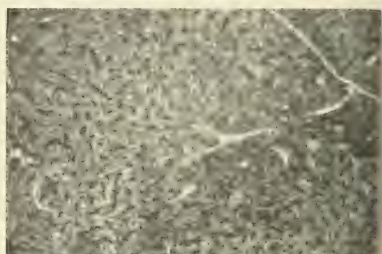
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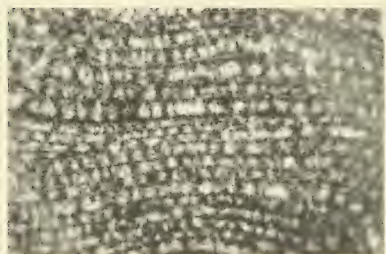
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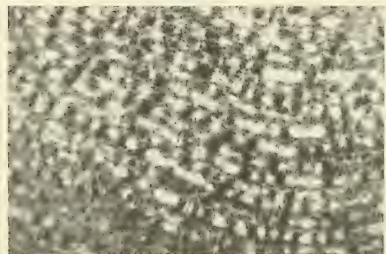
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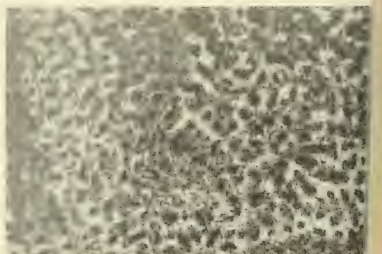
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EXPLANATION OF PLATE 8

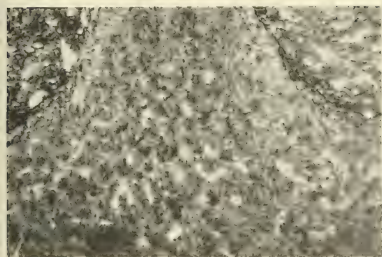
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Figure	Page
1. Anostylostroma spissa Birkhead, n. sp.	44
a. Vertical section through low domal mamelon containing astro- rhizal canals. b. Tangential section showing dark, fibrous, ver- micular-shaped pillars. c. Vertical section with laminae appearing as light lines, pillar and secondary tissue darker; the coenosteum grew around a coral of <i>Favosites</i> sp. d. Tangential section showing forking astrorhizal canals and astrorhizal tubes. Callaway Forma- tion, locality G (slides 310-26, 310-25, 310-21, 310-23). Holotype, No. 3630.	
2. Stictostroma ozarkense Birkhead, n. sp.	47
a. Vertical section; pillars short, transversely fibrous; some laminae with light median layer of tissue. b. Tangential section; pillars round, becoming vermicular in mamelon areas; central tube of mamelon is shown in center part of figure. Grand Tower Forma- tion, locality O (slide 312-01). Holotype, No. 3631.	
3. Stictostroma ordinarium Birkhead, n. sp.	48
a. Vertical section; laminar tissue lighter in color than pillar tissue; pillars confined to one interlaminar space, a few superposed. b. Tangential section; pillars round, some elongate; galleries anasto- mose around pillars. Callaway Formation, locality A (slides 310-32, 310-33). Holotype, No. 3653.	

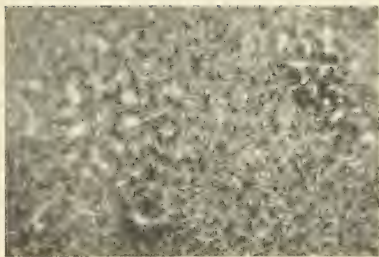
EXPLANATION OF PLATE 9

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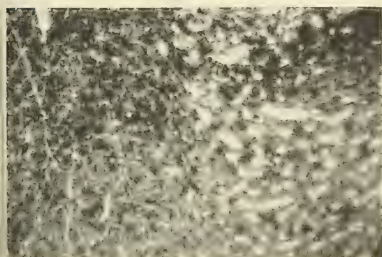
Figure		Page
1.	Stictostroma planulatum Birkhead, n. sp.	49
	a. Vertical section through mamelon; pillars and laminae difficult to distinguish; galleries irregularly shaped. b. Tangential section; most of section is tissue; gallery spaces mark positions of mamelons; pillars have black median area, some ring-pillars in mamelon areas. Callaway Formation, locality A slides 310-34, 310-37). Holotype, No. 3634.	
2.	Stromatoporella cryptomamillata Birkhead, n. sp.	58
	a. Vertical section through mamelon; gallery space occurs between mamelons; segments of astrorhizal tubes are seen in the mamelon; laminae curve sharply upward into mamelons. b. Tangential section; ring of gallery spaces marks position of mamelon; ring-pillars located in and away from mamelon areas; small segments of astrorhizal canals present adjacent to central mamelon tube. Callaway Formation, locality G (slides 310-52, 310-51). Holotype, No. 3639.	
3.	Stromatoporella congregabile Birkhead, n. sp.	52
	a. Vertical section; pillars thick, laminae both regular and irregular; some galleries U-shaped near base of figure. b. Tangential section; astrorhiza in lower left part of figure, with short, forked canals radiating from a central tube; pillars round, coalescent, ring-pillars prominent near astrorhizal areas. Callaway Formation, locality G (slides 310-100, 310-42). Holotype, No. 3635.	
4.	Stromatoporella ozoraensis Birkhead, n. sp.	57
	a. Vertical section; laminae regular, abruptly upturned to form ring-pillars superposed; regular pillars short, few superposed. b. Tangential section showing round and vermicular regular pillars and ring-pillars. Grand Tower Formation, locality O (slides 310-48, 310-49). Holotype, No. 3638.	



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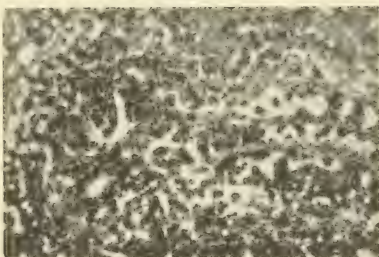
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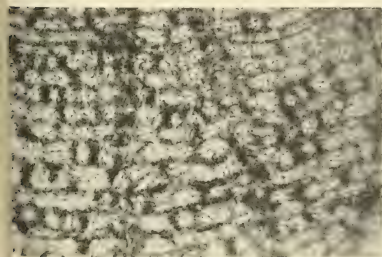
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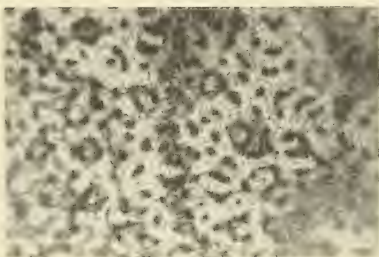
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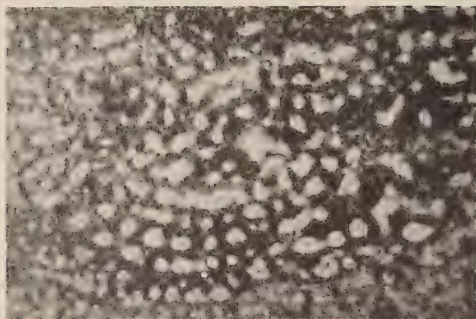
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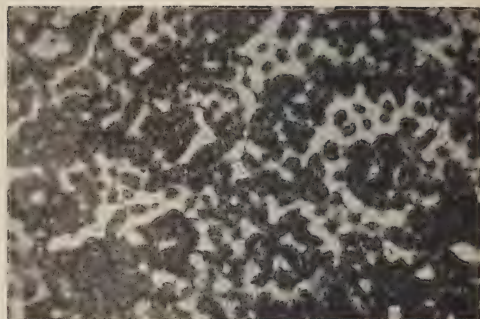
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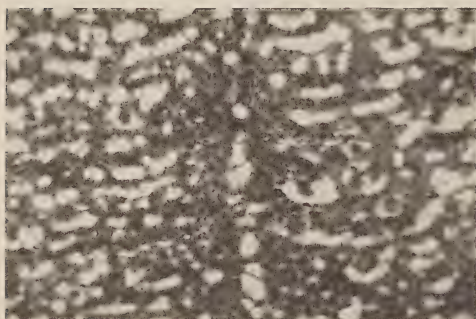
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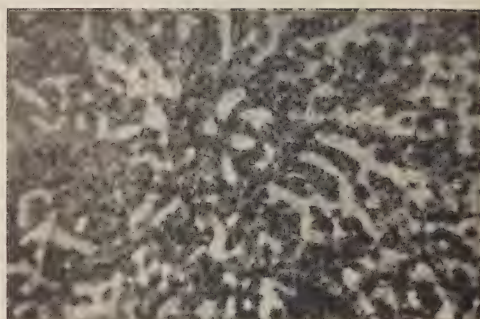
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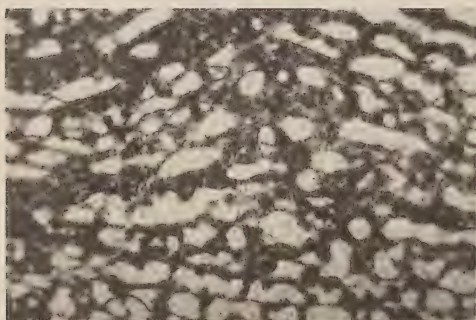
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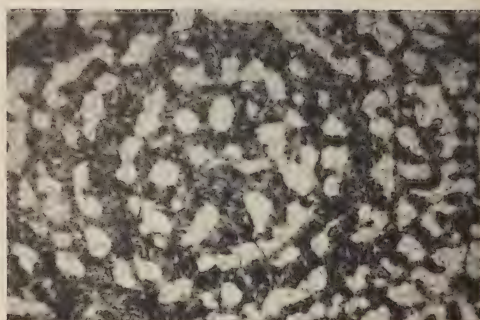
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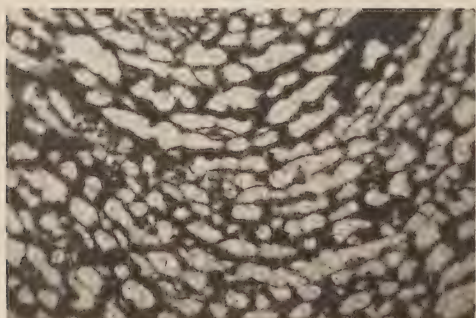
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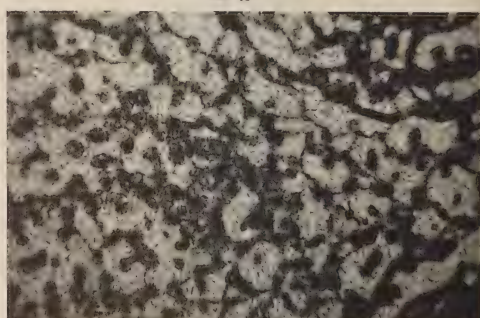
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EXPLANATION OF PLATE 10

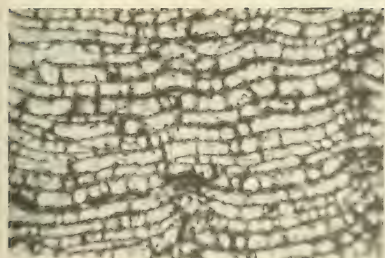
All figures are times 10.

Figure	Page
1. <i>Stromatoporella indubia</i> Birkhead, n. sp.	56
a. Vertical section; laminae regular and irregular; galleries irregularly oval. b. Tangential section; tubular tissue; thick-walled ring-pillars present, some pillars joined by dissepiments; clear areas of pin-point size in tissue are cross sections of tubules. c. Vertical section through mamillar column; dissepiments divide mamillar tube, forming a pseudozooidal tube. d. Tangential section of an astrorhiza; multiple central tubes shown with short, thick, anastomosing canals radiating from central area. Callaway Formation, locality A (slides 310-46, 310-47). Holotype, No. 3637.	
2. <i>Stromatoporella turbata</i> Birkhead, n. sp.	54
a. Vertical section through low, domal mamelon column; longer galleries probably astrorhizal canals. b. Tangential section across mamelon; annuli of laminae which turn upward to form mame-lons are apparent; multiple mamelon tubes shown in central part of figure. c. Vertical section of area between two mamelon columns; irregularity of laminae shown; dissepiments common. d. Tangential section; round pillars shown, many connected by dissepiments; ring-pillars in or adjacent to laminae. Callaway Formation, locality G (slides 310-43, 310-44, 310-45). Holotype, No. 3636.	

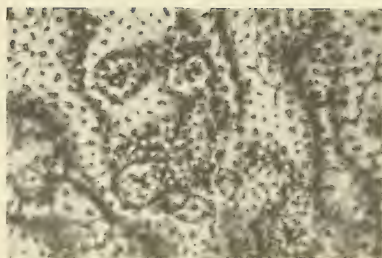
EXPLANATION OF PLATE 11

All figures are times 10.

Figure	Page
1. <i>Stromatoporella foraminosa</i> Birkhead, n. sp.	51
a. Vertical section showing variation in thickness of laminae; mamillar column at right edge of figure. b. Tangential section showing round regular pillars, ring-pillars, and anastomosing gallery space; annular rings of laminae mark positions of mamillae. Snyder Creek Shale, locality K (slides 312-03, 310-31). Holotype, No. 3628.	
2. <i>Trupetostroma vesiculosum</i> (Stearn)	62
a. Vertical section; pillars long, dominant over laminae; extensive development of dissepiments shown. b. Tangential section; pillars round; mamelon areas marked by annuli of laminae (right edge of figure); tissue of dissepiments forms gray, porous film over parts of section. Callaway Formation, locality A (slides 310-55, 310-56). Hypotype, No. 3641.	
3. <i>Trupetostroma adriani</i> Birkhead, n. sp.	63
a. Vertical section showing mamelon tube crossed by microlaminae, forming pseudozooidal tube. b. Tangential section across mamelon showing central tubes of mamelon. c. Vertical section; dark median microlaminae of laminae well developed in area of section; laminar and pillar tissue confluent. d. Tangential section; pillars anastomosing; galleries oval to circular. Four figures are shown to illustrate differences which occur within an individual coenosteum. Callaway Formation, locality B (slides 310-58, 310-60, 312-04). Holotype, No. 3642.	



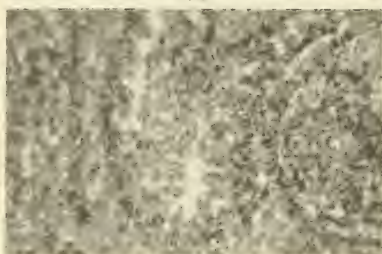
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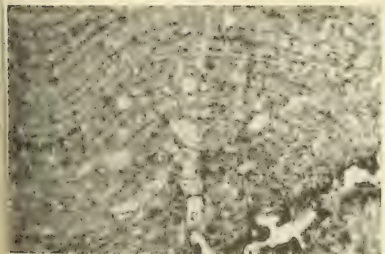
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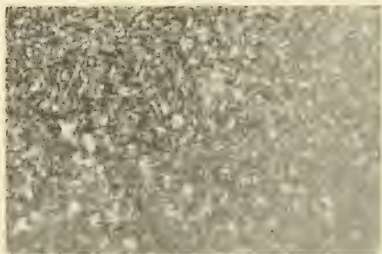
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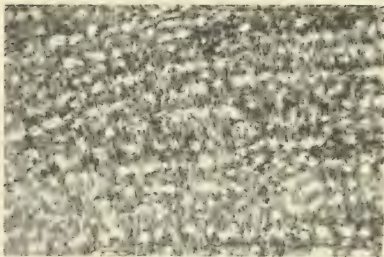
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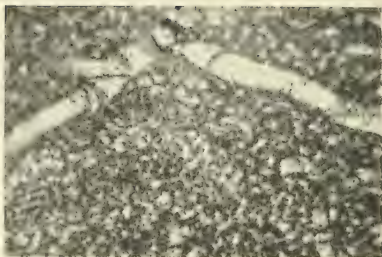
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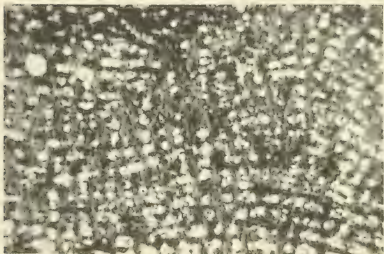
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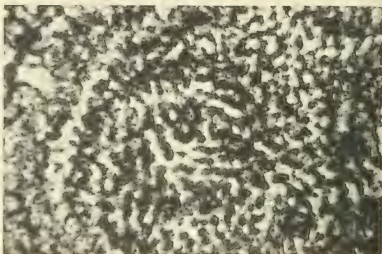
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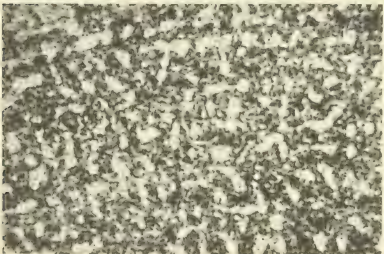
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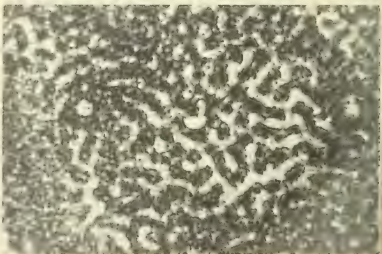
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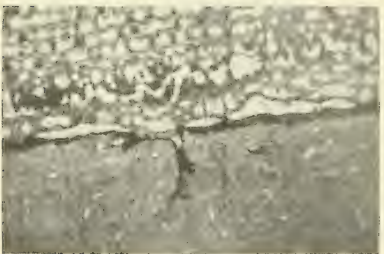
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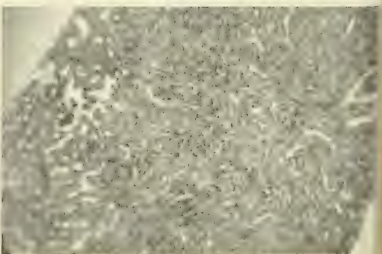
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EXPLANATION OF PLATE 12

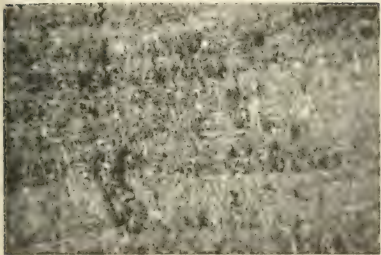
All figures are times 10.

Figure	Page
1. Trupetostroma kennissoni Birkhead, n. sp.	64
a. Vertical section showing confluent pillar and laminar tissue, laminae more or less indicated by rows of galleries. b. Tangential section through part of an astrorhiza; astrorhizal canals large, bifurcating, crossed by dissepiments, and radiate from a small central tube; pillars round, vermicular, and some coalesce to form rings. Callaway Formation, localities E and H (slides 310-62, 310-63). Holotype, No. 3643.	
2. Trupetostroma ideale Birkhead, n. sp.	60
a. Vertical section; laminae thin; pillars short, many superposed. b. Tangential section; pillars round, coalescent, form chainlike circles; vague astrorhiza near center of figure, with short, thick canals. Callaway Formation, locality N (slides 310-53, 310-54). Holotype, No. 3640.	
3. Ferestromatopora turbinata Birkhead, n. sp.	66
a. Vertical section; tissue coarsely maculate; laminae regular over parts of figure but irregular over most of figure; galleries and pillars irregular. b. Tangential section; pillars vermicular, coalescent, some coalesce to form rings; coarse maculae give flocculent aspect to tissue. Callaway Formation, locality J (slides 310-66, 310-67). Holotype, No. 3644.	
4. Stromatopora granata Birkhead, n. sp.	70
a. Vertical section encrusted by <i>Stromatoporella congregabile</i> ; tissue finely maculate, laminar and pillar tissue amalgamated; galleries sparse; astrorhizal canals circular in cross section; note dark, basal peritheca of <i>Stromatoporella congregabile</i> . b. Tangential section; part of astrorhiza visible in upper right corner of figure, canals fork, interconnect with those of adjacent astrorhizae (left side of figure). Callaway Formation, locality G (slides 310-77, 310-78). Holotype, No. 3647.	

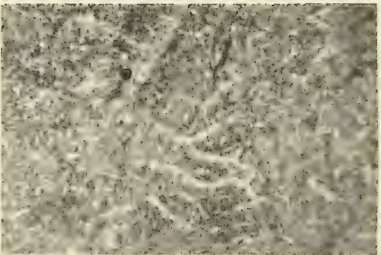
EXPLANATION OF PLATE 13

All figures are times 10.

Figure	Page
1. <i>Stromatopora congrua</i> Birkhead, n. sp.	68
a. Vertical section; tissue maculate; pillar and laminar tissue amalgamated; galleries scarce; cross sections of astrorhizal canals are small and circular. b. Tangential section; segments of interconnecting astrorhizal canals seen in central part of figure. Callaway Formation, locality A (slides 310-71, 310-72). Holotype, No. 3646.	
2. <i>Stromatopora indistincta</i> Birkhead, n. sp.	69
a. Vertical section; tissue maculate, badly altered; pillar and laminar tissue amalgamated; vague astrorhizal canals seen in right side of figure. b. Tangential section; tissue badly altered, maculate; most of section is tissue, but a few circular galleries are visible. Callaway Formation, locality A (slides 310-74, 310-76). Holotype, No. 3645.	
3. <i>Syringostroma astrorhizoides</i> Birkhead, n. sp.	73
a. Vertical section; maculae arranged in horizontal layers, forming microlaminae; laminae undulate into broad mamelons which contain astrorhizal canals. b. Tangential section of astrorhiza; bifurcating canals radiate from a central tube. c. Vertical section of superposed astrorhizae. d. Tangential section showing large round pillars and segments of astrorhizal network. Callaway Formation, locality G (slides 310-79, 310-80, 310-82, 310-83). Holotype, No. 3650.	



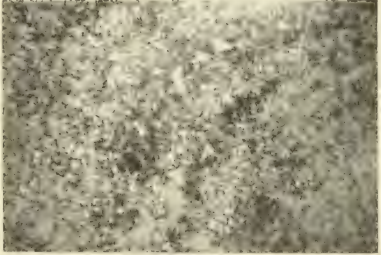
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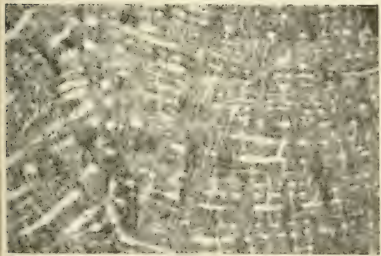
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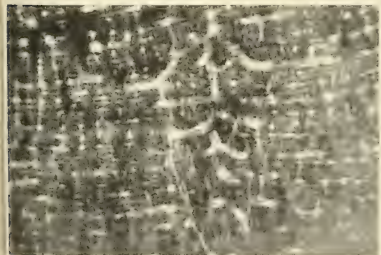
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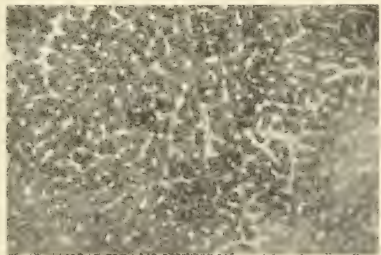
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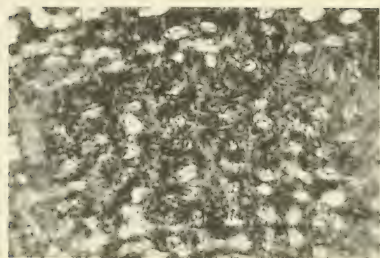
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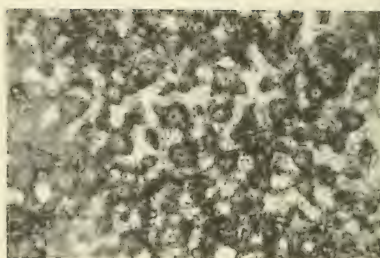
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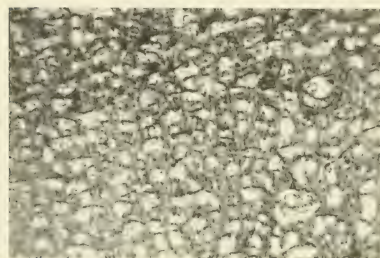
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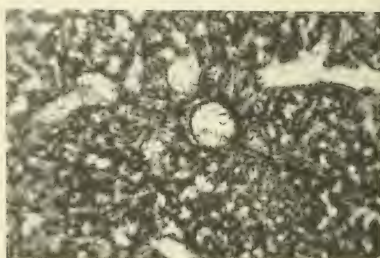
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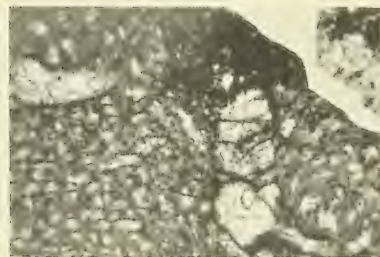
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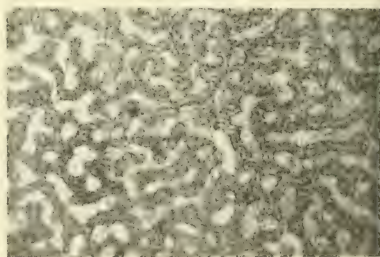
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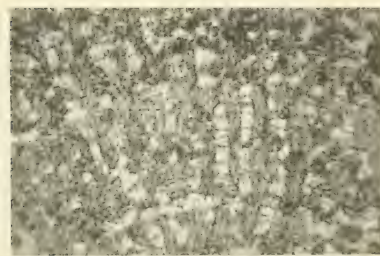
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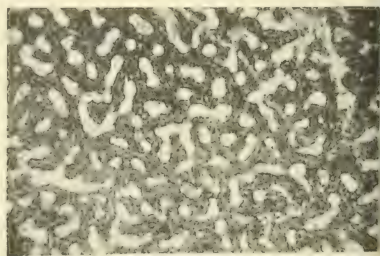
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EXPLANATION OF PLATE 14

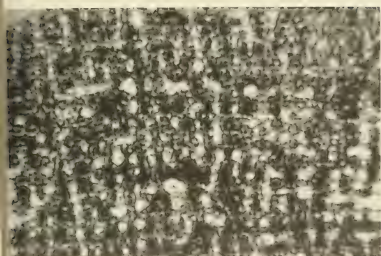
All figures are times 10.

Figure	Page
1. Taleastroma pachytexta (Lecompte)	72
a. Vertical section; pillars long, extend through laminae; edges of pillars composed of maculate tissue. b. Tangential section; pillars large, round, centers of compact tissue; galleries anastomosing. Callaway Formation, locality C (slides 310-90, 312-05). Hypotype, No. 3651.	
2. Parallelopora dartingtonensis (Carter)	75
a. Vertical section showing coarse vertical tubules in tissue of pillars, ragged appearance of galleries, and numerous dissepiments. b. Tangential section; part of large astrorhiza shown, with large central tube from which radiate bifurcating canals; tissue maculate; pillars coalescent. c. Vertical section through axial tube of astrorhiza, tube divided by dissepiments; canals can be seen leading away from axial tube. Callaway Formation, locality H (slides 310-84, 310-85, 310-86). Hypotype, No. 3648.	
3. Parallelopora catenaria Birkhead, n. sp.	77
a. Tangential section through vague astrorhiza (right side of section), segments of canals visible, appear to radiate from axial tube. b. Vertical section showing long pillars; superposed galleries crossed by microlaminae, forming pseudozooidal tubes. c. Tangential section; coalescent pillars form chainlike network; galleries oval and irregular in shape; large maculae of tissue well illustrated in this figure. Callaway Formation, locality A (slides 310-87, 310-88). Holotype, No. 3649.	

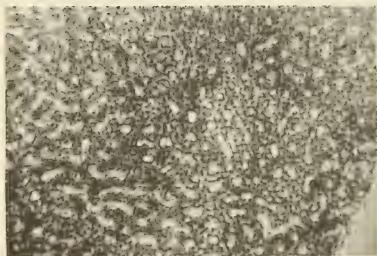
EXPLANATION OF PLATE 15

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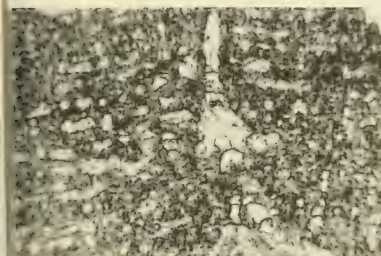
Figure	Page
1. Hermatostroma insulata Birkhead, n. sp.	78
a. Vertical section showing vague, light-colored sheaths of vesicular tissue around pillars. b. Tangential section showing coalescent pillars, vesicular sheaths around pillars, and vermicular galleries. c. Vertical section of superposed astrorhizae, with axial tubes distinctly shown; dissepiments in tubes. d. Tangential section showing network of astrorhizal canals at right and left sides of figure. Callaway Formation, locality M (slides 310-92, 310-95, 310-96). Holotype, No. 3652.	
2. Pseudoactinodictyon mineolaensis Birkhead, n. sp.	82
a. Vertical section; pillars and laminae indistinct, tissue confluent; dissepiments make framework for maculate tissue; galleries irregular. b. Tangential section showing oval and elongate galleries, and coalescent pillars; laminar and pillar tissue indistinguishable. c. Vertical section through low, domal mamelon on which astrorhizae are located; dissepiments cross astrorhizal canals. d. Tangential section across astrorhiza; multiple axial tubes present with segments of canals radiating from them. Callaway Formation, locality G (slides 311-05, 311-06). Holotype, No. 3654.	



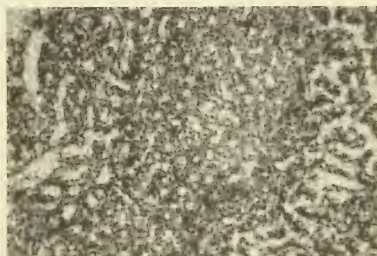
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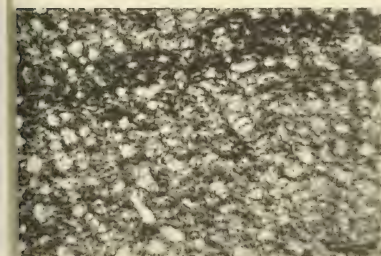
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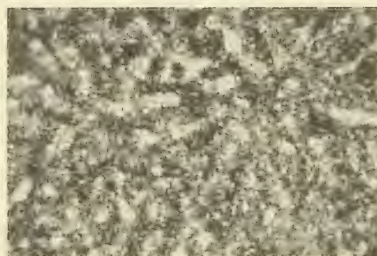
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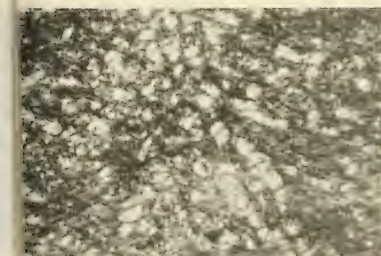
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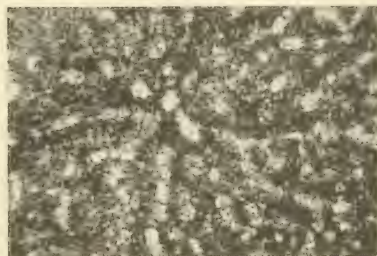
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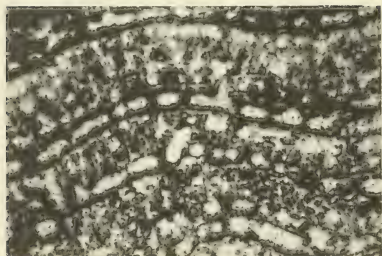
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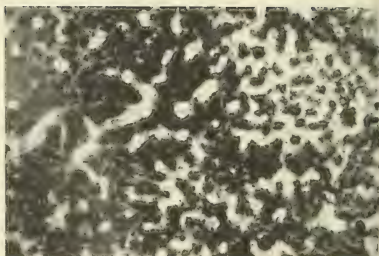
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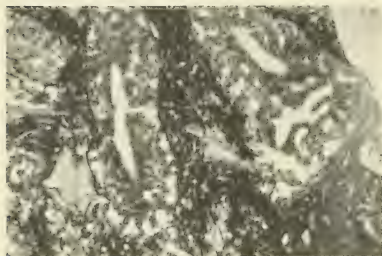
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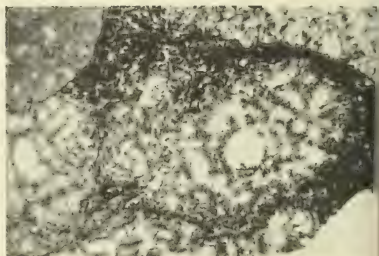
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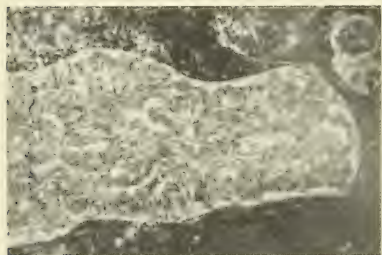
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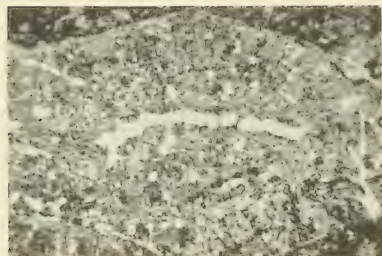
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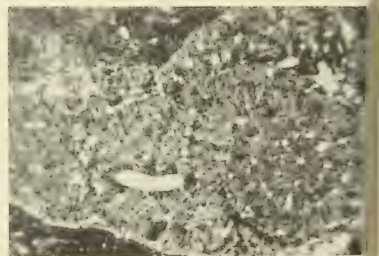
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EXPLANATION OF PLATE 16

All figures are times 10.

Figure	Page
1. <i>Clathrocoilona subclathrata</i> Galloway and St. Jean	80
a. Vertical section; tripartite laminae developed in part of section (note lamina which extends unbroken across top of figure); latilaminae developed as a result of repetition of structures, bottom two laminae of each latilamina enclose gallery spaces which are longer than galleries of succeeding laminae (may be layer of astrorhizal canals). b. Tangential section; pillars round, some coalescent; galleries anastomosing; segments of astrorhizal canals seen in left half of figure. Callaway Formation, localities G, K, M (slides 310-97, 312-06). Hypotype, No. 3653.	
2. <i>Amphipora ramosa</i> (Phillips)	84
a. Axial sections showing axial canals and peripheral development of pillars and galleries; coenosteum at right side of figure is branching. b. Cross sections of open forms of <i>Amphipora</i> showing dark, fibrous tissue of thin, anastomosing pillars, and the large axial canals. Callaway Formation, localities A and G (slides 311-09, 311-13). Hypotype, No. 3655.	
3. <i>Stachyodes crebrum</i> Stearn	86
a. Oblique axial section; tubules in tissue; coenosteum sheathed in clear calcite; pillar and laminar tissue amalgamated. b. Cross sections, one of which (central specimen) is encrusted by <i>Clathrocoilona</i> sp.; multiple axial tubes are apparent; cross sections of tubules appear as small pores on section. Callaway Formation, localities A, E, G, H (slides 311-07, 311-08). Hypotype, No. 3656.	
4. <i>Stachyodes spongiosum</i> Stearn	87
a. Axial section showing axial canal crossed by dissepiments (microlaminae). b. Axial and cross section through same coenosteum, demonstrating branching growth. Callaway Formation, localities A, E, G, H (slides 311-10, 311-14). Hypotype, No. 3657.	

INDEX

Volume 52, Number 234

NOTE: Light face figures refer to pages. Heavy face figures refer to plates.

A			
abeona,		Clemson University ..	24
Clathrocoilona	80	coalescens,	
Actinodictyon	23, 32, 82	Trupetostroma	65
Adrian Quarry	64	Coelenterata	35
adriani,		Columbus Formation..	30
Trupetostroma ....11	63, 64	columnare,	
Alberta, Canada	23	Anostylostroma	42
Amphipora	23, 31, 32, 83	confertum,	
anacolumna,		Clathrodictyon	39
Anostylostroma	43	congregabile,	
Anostylostroma	23, 31, 32, 40,	Stromatoporella ....9	52, 53, 54, 71
49, 58, 85		congrua,	
antiquatus,		Stromatopora ....13	68, 69, 71
Cryptophragmus	24	Cooper facies	27
Ashland facies	27	costulata, Stachyodes .	88
astrorrhizoides, Syringo-		crebrum,	
stroma ....3, 4, 13	70, 73, 74	Stachyodes	16 81, 85, 86, 87
Atelodictyon	39	cryptoannulata,	
Auburn Limestone	25	Stromatoporella	54, 57
		cryptomamillata,	
		Stromatoporella ....9	58, 59
		Cryptophragmus	24, 25
		Cryptozoön	5 24
		cummingsi,	
B		Stromatopora	71
bassleri,		Cyrene Member	25, 26, 28, 31,
Trupetostroma	64	37, 39, 40	
Beauvais Sandstone ..	27	cyrenensis,	
Beckett Formation	24	Clathrodictyon 6	38, 39, 40
Belgium	23, 73	Cystiphyllum	87
bifurcacolumnare,			
Anostylostroma ....7	41, 42	D	
Biostromes	25	dartingtonensis,	
Bloomsdale		Parallelopora	3, 14, 28, 75,
Formation	24	76	
Branson, E.B.	23, 25, 27	densum,	
		Syringostroma	73, 75
C		Devonian	26
Callaway Formation ..	23, 26, 27, 28,	Dinant Basin,	
30, 42, 43, 45,		Belgium	23
46, 52, 54, 55,		divergens,	
57, 59, 61, 63,		Stromatopora	75
64, 65, 67, 69,		dupontense,	
70, 71, 73, 75,		Anostylostroma	43
76, 78, 79, 81,			
85, 87, 88		E	
callawayensis,		Edgewood	
Anostylostroma 3, 7	42, 43, 46,	Formation	23, 25, 28, 31,
49, 62, 63		37, 39, 40	
Cape Girardeau,		28, 30	
Missouri	26	Eifelian	
catenaria,		elevatum,	
Parallelopora ....4, 14	77, 78	Stictostroma	50
Clathrocoilona	79	excellens,	
Clathrodictyon	23, 32, 36, 38,	Stromatoporella	55
39			

F

fastigiatum,	
Clathrodictyon	40
Favosites	27, 42, 43, 54, 64, 70, 73, 78, 85, 87, 88
Ferestromatopora	65, 66
foraminosa,	
Stromatopo-	
rella	3, 11 30, 51, 52, 81
Frasnian	23, 28, 30

G

Galloway, J. J.	24, 25, 30, 31, 32
Gealy, J. R.	26, 28
Germany	75, 82, 86
Gerronostroma	58
Givetian	23, 28
granata,	
Stromatopora	12 54, 70, 71
Grand Tower	
Formation	23, 26, 27, 28, 31, 48, 58
granulata,	
Stromatopora	51
Stromatoporella	57, 58

H

Hager Formation	24
Halysites	28, 37
hamiltonense,	
Anostylostroma	41
Heliolites	26, 28
Hermatostroma	78
Hexagonaria	27
Holt's Summit,	
Missouri	65
Howe, W. B.	24, 25, 26, 27
Hydrozoa	35

I

ideale,	
Trupetostroma	3, 12, 60, 61
Idiostroma	23, 31, 32
incongruum,	
Clathrodictyon 3, 6	36, 37, 38
Indiana	23, 28, 30
indistincta,	
Stromatopora	13 69, 70
indubia, Stromatopo-	
rella	3, 4, 10 56, 57
insolitum,	
Gerronostroma	58
insulata,	
Hermatostroma ..	15 78, 79
Iowa	23

J

Jefferson City	
Formation	25

Jeffersonville	
Formation	23, 30
jeffersonvillense,	
Stictostroma	48, 49, 54, 55
Joachim Formation ...	25
Jonesboro quadrangle,	
Missouri	26
juxi, pseudo-	
actinodictyon	82

K

kayi, Stictostroma	50
Kelleys Island, Ohio ..	73
Kennisson Quarry	65
kennissoni,	
Trupetostroma ..	12 64, 65, 77
Kentucky	30
Keyes, C. R.	23
Koenig, J. W.	25, 26, 27
krupennikovi,	
Ferestromatopora ..	66
Kuznetz Basin,	
Russia	66, 80

L

Labechia	26
laminosa,	
Stromatopora	69, 74
Larson, E. R.	23, 24
laxum,	
Anostylostroma	48
Lincoln County,	
Missouri	25
Little Saline	
Formation	26, 27
Logansport, Indiana ..	71
Logansport	
Limestone	23, 71, 81
logansportense,	
Hermatostroma ...	79
Lyellia	4 26, 28
Lyonsia	37

M

maculosum,	
Clathrodictyon	6 31, 36, 39, 40
Macy Formation	24
mamillatum,	
Clathrodictyon	6 37, 38
mamilliferum,	
Stictostroma	46
Manticoceras	27
Maquoketa	
Formation	25, 26
mediale,	
Anostylostroma	42
microcolumnare,	
Anostylostroma	52
Mineola facies	23, 27, 30, 83
mineolaensis, Pseudo-	
actinodictyon	15 31, 82, 83

- Missouri Geological Survey .. 24, 25
- N**
- Noix oolite 25
- norrisi, Pseudoactinodictyon 83
- O**
- obscura, Stromatopora 70
- Ohio 28, 30
- Onondagan 28
- Ontario 28
- ordinarium, Stictostroma 8 46, 48, 49
- Ordovician 24, 25
- ostiolata, Parallelopora 75, 78
- ozarkense, Stictostroma 8 47, 58,
- Ozora Quarry 26
- ozoraensis, Stromatoporella 3, 9 31, 57, 58
- P**
- pachytexta, Taleastroma 14 72
- Parallelopora 75
- parasolitaria, Stromatoporella 52
- Parks, W. A. 23, 27
- planulatum, Stictostroma 9 49, 50, 53, 54, 57, 59
- Plattin Limestone 24, 25
- Port Colborne, Ontario 46
- Pseudoactinodictyon .. 23, 32, 82
- R**
- ramosa, Amphipora 16 49, 54, 84, 85, 87
- rareicystosum, Trupetostroma 64
- Rowley, Robert R. 25
- S**
- Savage, T. E. 23, 25, 28
- schlüteri, Hermatostroma 79
- Sexton Creek Formation 23, 25, 28, 38
- Silurian 25
- Snyder Creek Formation 23, 26, 27, 30, 52, 81
- spissa, Anostylostroma 8 44, 45
- spongiosum, Stachyodes 16 43, 49, 54, 77, 85, 87, 88
- Stachyodes 23, 31, 32, 85
- St. Clair, Stuart 27
- St. Jean, J., Jr. 24, 31
- Stearn, C. W. 87
- Stictostroma 31, 46, 51, 58
- Stromatolites 25
- Stromatopora 27, 31, 65, 66, 68
- Stromatoporella 31, 32, 49, 50
- Stromatoporoidea 35
- subclathrata, Clathrocoilonia 16 30, 31, 32, 54, 71, 80, 81
- Synthetostroma 32
- Syringostroma 73
- T**
- Taleastroma 71, 79
- Tioughniogan 28
- Trupetostroma 23, 27, 31, 32, 43, 60, 63, 88
- tuberculata, Stromatoporella 58
- turbata, Stromatoporella 10 54, 55
- turbinata, turbinata, Ferestromatopora 12 66, 67
- Tyrgan, Russia 66
- tyrganensis, Ferestromatopora .. 67
- U**
- University of Missouri 24
- University of North Carolina 24, 32
- Unklesbay, A. G. 24, 27
- V**
- vagans, Pseudoactinodictyon 83
- vermiculosum, Anostylostroma 7 45, 46
- verticillata, Stachyodes 86, 87, 88
- vesiculosum, Clathrodictyon 25, 36, 37, 38, 39
- Trupetostroma 11 28, 62, 63
- W**
- Wabaunsee Group 25
- warreni, Trupetostroma 61
- Weller, Stuart 27
- Wheeler, Walter H. 24

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**LATE TERTIARY BIOSTRATIGRAPHY
(PLANKTONIC FORAMINIFERA) OF TROPICAL
INDO-PACIFIC DEEP-SEA CORES**

By

FRANCES L. PARKER

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FRANCES L. PARKER
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CONTENTS

	Page
Abstract	115
Introduction	115
Boundaries ...	116
Past zonations for tropical areas	117
Previous work ..	124
Location of cores and sampling methods	125
Biostratigraphy of Indo-Pacific cores	126
Introduction ..	126
Description of zones ..	136
Ecological observations ..	140
Systematic descriptions ..	141
Introduction	141
Descriptions ..	144
Family Candeinidae: <i>Candeina</i> , <i>Globigerinita</i> , <i>Turborotalita</i> ..	144
Family Hantkeninidae: <i>Globanomalina</i> ..	147
Family Globigerinidae: <i>Globigerina</i> , <i>Globigerinella</i> , <i>Globigerinoides</i> <i>Hastigerina</i> , <i>Orbulina</i> , <i>Sphaeroidinella</i>	148
Family Catapsydracidae: <i>Globoquadrina</i> , <i>Pulleniatina</i>	162
Family Globorotaliidae: <i>Globorotalia</i> ..	174
References ..	183
Plates ..	187

TEXT-FIGURES

1. Comparison of zonations and boundaries	118
2. Species ranges and evolutionary sequences	121
3. Age determinations and zonation of deep-sea cores	132
4. Evolutionary series of <i>Globigerinoides fistulosus</i> (Schubert) ..	155
5. Early growth stages of <i>Globigerinoides sacculifer</i> (Brady)	158

TABLES

1. Locations and zonation of deep-sea cores, Fiji samples, and a dredge haul ..	128
2. Species ranges in CAP 38 BP, with age determinations and zonation	133
3. Species ranges in PROA 88 P and LSDH 78 P, with age determinations and zonation	134
4. Species ranges in DODO 57 P, DODO 117 P and DODO 141 G, with age determinations and zonation ..	135

LATE TERTIARY BIOSTRATIGRAPHY
(PLANKTONIC FORAMINIFERA) OF TROPICAL
INDO-PACIFIC DEEP-SEA CORES¹

FRANCES L. PARKER

Scripps Institution of Oceanography

ABSTRACT

Upper Miocene and Pliocene sections of 18 cores, 1 dredge sample and 5 samples from Fiji have been analyzed. The Banner and Blow (1965b, 1967) zonation seems best suited for this part of the section in the tropical Indo-Pacific area, with the possible exception of their Zone N.20. The zonations of Bandy (1963a, b, 1964b), Bolli and Bermúdez (1965; Bolli, 1966a), and McTavish (1966) are compared and analyzed. Boundary problems are discussed. The Miocene-Pliocene boundary is placed between Banner and Blow's Zones N.18 and N.19 (slightly higher than its placement in a rigid sense), the Pliocene-Pleistocene boundary between Zones N.21 and N.22. An interesting ecological feature is the first appearance in Zone N.21 (upper Pliocene) of temperate species such as *Globigerina falconensis* and *Globorotalia inflata*, possibly *G. tosaensis*, which are known to range lower elsewhere. Evolutionary sequences have been defined, when possible, including species of *Globoquadrina*, *Pulleniatina*, *Spaeroidinella*. Generic classification problems are discussed. The subfamily Candeininae is raised to family status. *Pulleniatina* is placed in the Catapsydracidae. The polyphyletic genus *Turborotalia* is included in *Globorotalia*, but *Globigerinoides* is retained pending additional study. *Globoquadrina* is emended to include related, pitted-wall species having umbilical-extraumbilical apertures and apertural teeth. Four new species are described: *Globanomalina praepumilio*, *Globigerina praedigitata*, *Globoquadrina pseudofoliata*, and *Globorotalia anfracta*.

INTRODUCTION

This study was undertaken originally to find a workable zonation for the upper Miocene and Pliocene in deep-sea cores of the Pacific and Indian Oceans. While the work was in progress at least four zonations which include this part of the section appeared: Bandy (1963a, b, 1964b); Banner and Blow (1965b, 1967); Bolli and Bermúdez (1965; Bolli, 1966a) and McTavish (1966). As a result, the emphasis was shifted to testing these zonations and finding out whether or not they were applicable in the Pacific-Indian Ocean region. In addition, a study of the species in this part of the section has been made along similar lines to that on Recent species made earlier (Parker, 1962). In this case, however, only species which lived in tropical areas are included, because the available cores lie within the tropics. Later, it is hoped to make a comparison of the results found there with sequences from colder regions as well as from the Atlantic.

W. R. Riedel provided a list from which appropriate cores were chosen. H. A. Lowenstam supplied material from Fiji; C. G. Adams kindly sent from the collection of the British Museum (Nat. Hist.) a

¹ Contribution from the Scripps Institution of Oceanography, University of California, San Diego, California

sample of Brady's type material for his species "*Pulvinulina menardii* var. *tumida*" and "*Globigerina sacculifera*"; D. B. Ericson provided samples from the Lamont Core V3-153; Miss A. R. Messina sent from the collection of the American Museum of Natural History a sample of type material of de Amicis (1895) and Silvestri (1904) from the "Trubi" beds of Sicily. J. L. Lamb kindly sent specimens which were helpful in working out the *Globoquadrina dutertrei* evolution. Other acknowledgments for specimens sent are given in the systematic discussions. M. N. Bramlette, W. H. Blow, H. M. Bolli, and D. G. Jenkins have been helpful in many ways. F. T. Banner and W. H. Blow kindly supplied me with a manuscript of their paper on *Pulleniatina* (Banner and Blow, 1967). B. M. Funnell helped with the preliminary examination of the Indian Ocean cores.

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BOUNDARIES

So far, it has proved impossible to correlate the Miocene-Pliocene boundary in Italy with sections elsewhere by means of planktonic Foraminifera. The Italian type Pliocene was laid down under marginal marine conditions into which many planktonic species then living in the Mediterranean probably did not penetrate. Thus, there are few species of the globorotaliids and no representatives of the sphaeroidinellid species. As a result, there appears to be no firm basis for correlation with the tropical faunas. In Sicily, however, the conditions are more promising. The so-called "Trubi" beds of Sicily represent the lowermost Pliocene. They are Zanclean in age (correlative with the Tabianian of Italy), the Messinian Stage of uppermost Miocene being the next older stage in the Sicilian section (Selli, 1964; E. and M. Tongiorgi, 1964). Several samples of "Trubi" material have been examined, most of which yielded nothing conclusive. However, one collected by A. R. Loeblich, Jr., at the type locality of de Amicis (1895) and Silvestri (1904) contains an excellent planktonic fauna which appears to be referable to Banner and Blow's Zone N.18, or possibly basal N.19. The fauna contains among other species: *Sphaeroidinella seminulina*, *S. subdehiscens*, and *Globorotalia inflata* [which grades into "*G. puncticulata*" (of Italian authors) at this locality]. Some specimens of *Sphaeroidinella subdehiscens* show slight

openings on the side opposite the apertural one which may be due to solution of calcium carbonate or which may represent the earliest stage in the development of *S. debiscens*. According to Blow (1959), the evolution from one species to the other is seen about 40 feet up in the 200 feet thick "Trubi" beds. Strictly speaking, then, the Miocene-Pliocene boundary occurs a short distance below that between Banner and Blow's (1965b) Zones N.18 and N.19, but for convenience the boundary between these two zones will be considered to represent the Miocene and Pliocene boundary also. The advantage in using this point is the ease in detecting this particular bit of evolution. In addition, apparently there is no index fossil for the actual boundary itself. Further discussion of evolutionary stages and their use in correlation will be given later in this paper.

The Pliocene-Pleistocene boundary is a difficult one to detect. In the Italian section, it has been suggested that the boundary be placed at the location of the first appearance of *Hyalinea balthica* (Schroeter) in rocks of Calabrian age, at Le Castella. Banner and Blow (1965b) stated that they have recognized their Zone N.22 in "the lower part of the stratotype Calabrian of Santa Maria di Catanzaro" described by Gignoux (1913) as typical of his Calabrian stage. For this reason, and for convenience, the Pliocene-Pleistocene boundary in this study is considered to be that between Banner and Blow's Zones N.21 and N.22. Discussions of Ericson, *et al.* (1963), Riedel, *et al.* (1963), Jenkins (1964), and Akers (1965) present some of the opinions and contradictory views concerning this boundary. As used here, the boundary is probably close to that of Ericson, *et al.*, although it may be somewhat higher if those authors included *Globorotalia tosaensis* in their concept of *G. truncatulinoides*. There is some doubt whether or not the Ericson, *et al.* boundary is a true one in all cases. In one of the cores which they used in locating their boundary—V3-153—there may be a disconformity at the depth where they put the boundary so that Quaternary lies on mid-Pliocene (Banner and Blow Zone N.20 or lowermost N.21). Text-fig. 1 shows the possible positions of the Ericson, *et al.* boundary, as well as that of Akers, in relation to the Banner and Blow zonation.

PAST ZONATIONS FOR TROPICAL AREAS

In the past few years zonations including the upper Miocene and Pliocene of tropical regions have been published by Bandy (1963a, b, 1964b), Banner and Blow (1965b, 1967), Bolli and Bermúdez (1965)

AGE	RANGES OF KEY SPECIES ACCORDING TO BANNER & BLOW (1965b, 1967)				Bandy (1963 a, b, 1964 b)	Bolli & Bermúdez (1965, 1966a)	BOUNDARIES				
MID MIOC	"Globorotalia (G.) merolimida"	"Globorotalia tumida pleistumida"	"Globorotalia (G.) tumida tumida"	"Sphaeroidinellopsis subdelhiscens (s.l.)"	Pontian	Miocene-Pliocene boundary ?	Miocene - Pliocene (This paper)	Pliocene - Pleistocene (This paper)			
			"Sphaeroidinella delhiscens delhiscens"								Pliocene - Pleistocene (Akers, 1965)
			"Pulleniatina obliquiloculata (s.s.)"								Miocene - Pliocene (This paper)
LATE MIOCENE		"Globorotalia (G.) multicaemera"						Miocene - Pliocene (Approximate correct position)			
PLIOCENE					possibly absent		Globoquadrina altispira Zone				
Quaternary							Globorotalia truncatulinoides Zone				
							Globoquadrina altispira/altispira altispira/altisp				

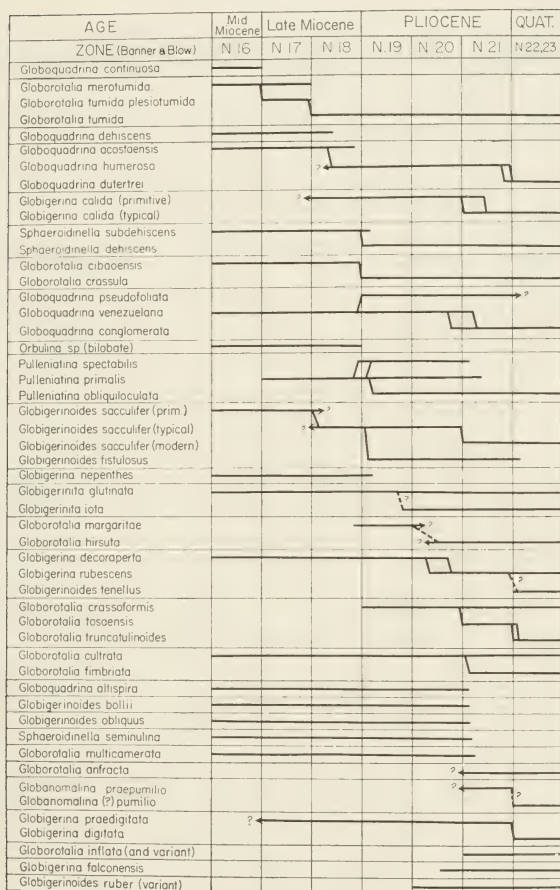
Text-figure 1. Comparison of Zonations and Boundaries

(Bolli 1966a), and McTavish (1966). After checking these zonations with the sections in the tropical Pacific Ocean and Indian Ocean cores, it appears that the Banner and Blow sequence is the most applicable, and it is used here as a basis for comparison (see Text-fig. 1). Zonations published for New Zealand and Australian sequences are omitted here because they are not applicable for the late Miocene and Pliocene period in the tropical regions covered by this paper, presumably because of the cooling of the water in those regions during that time. In the following discussion (and throughout the paper), names differing from these used in this paper are placed in quotation marks.

Bandy's zonation is somewhat difficult to correlate with that of Banner and Blow because the ranges of species, as given by the respective authors, do not always coincide. According to Bandy (1963b), the "right-coiling *Globorotalia* complex", at least part of which probably is synonymous with *G. multicamerata*, and *Globoquadrina altispira* s.l. became extinct at the same level. We must assume, therefore, that if Bandy included *Globorotalia tosaensis* in his *G. truncatulinoides*, which, according to him, makes its appearance at this level, then his base of the Pliocene must coincide with the base of Banner and Blow's Zone N.21; if he indeed meant *G. truncatulinoides*, then his Pliocene boundary coincides with the base of Banner and Blow's N.22. It is possible, that at higher latitudes *G. tosaensis* may range lower in the section (see also under Zone N.21 in "Descriptions of Zones") than it does in tropical areas, but such a range shift is not probable in the Philippine area (ca. lat. 11°N.) upon which Bandy (1964b) based this part of his zonation. A part of the section may be missing in the Philippine area studied, at least that part which includes Banner and Blow's Zone N.20, lying between the extinction level of *Globoquadrina altispira* and slightly below that of *Globorotalia multicamerata*. However, there is evidence in the Indo-Pacific cores that this zone is not always recognizable in this area (perhaps because of its brevity) because sometimes *G. altispira* ranges as high as *G. multicamerata*, even overlapping *G. tosaensis* slightly in some cases (see discussion under Zone N.20 in "Description of Zones"). Also, if *G. tosaensis* does not appear in the Philippine section, then Zone N.21 is missing. This zone is well developed in the Indo-Pacific cores. The top of Bandy's "Pontian" lies at or below the lower boundary of Zone N.21 (or N.20) and the base is at the extinction point of *Globigerina nepenthes*,

or perhaps roughly coincides with the basal boundary of Zone N.19. Probably Bandy's *Sphaeroidinella debiscens immatura* is equal to phylogenetically primitive *S. debiscens* (*q.v.*) of this paper, the datum used for the base of Zone N.19. In many of the cores, however, this species overlaps *Globigerina nepenthes*, which apparently it does not do in the Philippine section. Bandy's (1964b) "Sarmatian" must include Banner and Blow's zones from about the base of Zone N.19 down through Zone N.16 (upper middle Miocene) which lies just above the so-called "*Globorotalia mayeri*" Zone of authors, as defined by the upper range of "*G. mayeri*" (Cushman and Ellisor). This species, as interpreted by Bolli (1957) and others, includes in part the form referred by Banner and Blow (1965b) to "*G. siakensis*" (Le Roy) (Blow, personal communication), which became extinct at the base of Banner and Blow's Zone N.15, according to their definition. This part of the section (most of Zone N.16 and below) has not been studied in the cores, nor has special study been made of it elsewhere, so that the foregoing discussion is taken directly from the references mentioned. In the Philippines, Bandy marked the beginning of his "Sarmatian" by the extinction of *Globorotalia* "*altispira altispira*", a form of *G. altispira*, which ranges much higher in many areas, including the tropical Pacific and Indian Oceans (see Text-fig. 2).

Similar difficulties are encountered in trying to correlate McTavish's (1966) zonation in the Solomon Islands with Banner and Blow's. The simultaneous appearance of *Globorotalia tumida*, *Globigerinoides* "*quadrilobatus fistulosus*", *Globorotalia* "*cultrata fijiensis*" (= *G. multicamerata*), *Sphaeroidinella* "*debiscens debiscens*", *Globorotalia truncatulinoides*, *Globorotalia inflata*, and "*Globigerina conglomerata*" a whole zone ("*Sphaeroidinellopsis*" *seminulina* Zone) after the extinction of *Globigerina nepenthes* (whose range in his section is co-existent with that of *Globorotalia lenguaensis*) again suggests the presence of some kind of stratigraphic gap or gaps. McTavish's "*Globigerina dutertrei*" fauna seems to correlate with Banner and Blow's Zone N.21, based on the simultaneous appearances of *Globorotalia truncatulinoides* (or *G. tosaensis*) and *G. inflata*. However, the figured specimen of *G. truncatulinoides* (McTavish, 1966, pl. 5, figs. 16, 19, 20) appears to be *G. crassaformis* trans *tosaensis* and if this specimen represents his assemblage, the fauna could correlate with Zones N.19 or N.20. In addition, it is impossible to know exactly what discrete



Text-figure 2. Species Ranges and Evolutionary Sequences

The following species first occur in Zone N.17: *Candeina nitida*, *Globigerina* cf. *G. quinqueloba*, *Globigerinoides conglobatus*, *G. ruber*, *Globoquadrina hexagona*, *Globorotalia scitula*, *Hastigerina pelagica*, *Turborotalita humilis*. The following species occur throughout: *Globigerinella siphonifera*, *Globigerinita uvula*, "*Orbulina universa*." *Globigerinella adamsi* occurs only in the Recent.

faunas contained when the data are presented in a generalized range chart. Perhaps all species were not present in all samples and when the section of this area is studied further, more refinement of zonation will appear.

Bolli and Bermúdez' (1965; Bolli, 1966a) zonation also presents some correlation difficulties. Their "*Globorotalia*" *acostaensis* Zone apparently correlates with Banner and Blow's Zone N.16 and their "*G.*" *duertrei* Zone (= *Globoquadrina humerosa*?) apparently correlates, at least in part, with Zone N.17, although in the Indo-Pacific cores *G. humerosa* first appeared in Zone N.18 (see also systematics discussion on *G. humerosa*). There is a difference of opinion, however, between Bolli's (1966a) and Banner and Blow's (1967) correlation of the base of the *G. margaritae* Zone (a total range zone) with the Banner and Blow zonation. Bolli correlated the base of this zone with the upper part of Zone N.18, whereas Banner and Blow extended the range of this species down into the upper part of Zone N.16. Bolli and Bermúdez (1965) placed the lower boundary at 849 feet in Cubagua well 1 (type locality for this zone); the same point in this well lies in their Zone N.17 according to Banner and Blow (personal communication). Banner and Blow's published range of this species into Zone N. 16 is based on their belief that *Globorotalia* cf. *G. canariensis* (d'Orbigny) of Blow (1959, pl. 17, fig. 109) is synonymous with *G. margaritae* (Blow, personal communication). Bolli (personal communication) does not agree with this identification of the Pozón Formation species, saying that almost all specimens of *G. margaritae* are left coiling whereas the Pozón form is right coiling. In addition, he believes that the Pozón section is below the range of *G. margaritae*, as he observed that species elsewhere. *G. margaritae* occurs rarely in only two Pacific cores: in CAP 38 BP it first occurs in the upper part of Zone N.18 (this occurrence agrees with the range given by Bolli); in LSDH 78 P the species first occurs in the lower part of Zone N.19. The upper boundary of the *G. margaritae* Zone (or base of the *Globoquadrina* "*altispira altispira*" Zone) is found in Zone N.19, near the base of Zone N.20, according to both Bolli (1966a) and Banner and Blow (1967). The same is true in the Pacific core CAP 38 BP (in LSDH 78P the lower part of Zone N.19 is overlain by mixed Zone N.19 material and Quaternary). The scarcity of *G. margaritae* in the Indo-Pacific cores precludes the safe definition of this zone in this area.

The upper boundary of Bolli and Bermúdez' *Globoquadrina* "*altispira*

altispira" Zone is marked by the appearance of *Globorotalia truncatulinoides* at the base of the *Globoquadrina "altispira altispira"/Globorotalia truncatulinoides* Zone. This zone is not applicable in the Indo-Pacific deep-sea cores because in this region these two species do not overlap, although in some cores there is a short overlap of *Globoquadrina altispira* and *Globorotalia tosaensis*. There is some indication that *G. truncatulinoides* (*G. tosaensis*?) may overlap *Globoquadrina altispira* in the Gulf of Mexico. According to Akers (1965) *Globorotalia truncatulinoides* ranges below the extinction point of *Globigerina nepenthes*. Samples sent to W. R. Riedel (first processed and studied by W. H. Blow, and later lent to me for study) from the lower part of the SUBMAREX 6301 section (1410-1748 cm), stated by Bolli and Bermúdez in their original description of their *Globoquadrina "altispira altispira"/Globorotalia truncatulinoides* Zone to lie entirely within that zone, have been examined. The lower part, or possibly all, of that section represents a turbidite with strong graded bedding; there is some doubt about the upper part between 1410-1473 cm (W. R. Riedel, personal communication). The samples bear this out strongly. Found in this section are: Eocene globorotaliids, *Globoquadrina altispira*, *Globigerinoides obliquus* ("extremus" type), *G. bollii*, *Globorotalia multicamerata*, *G. miocenica*, as well as what appears to be a Quaternary assemblage containing *Globorotalia truncatulinoides* (in its typical form—not phylogenetically primitive), *Globigerinoides tenellus*, red *G. ruber*, red *Globigerina rubescens*, and *Globoquadrina dutertrei* (as interpreted in this paper). Bolli (personal communication) tells me that in his material he "saw no Eocene nor other clearly derived species". He believes the material considered here to be Quaternary is of the same age as his specimens of *G. "altispira altispira"*. It was hoped that the JOIDES Hole 3 material would clarify the Pliocene-Pleistocene Atlantic sequence, but Zone N.19 material is overlain by Quaternary in this section. In Lamont Core V3-153 from the Blake Plateau (28°24'N.; 77°56'W.; 970 m) *Globoquadrina altispira* s.l. and *Globorotalia truncatulinoides* (as well as *G. tosaensis*) do not overlap even though a large part of Banner and Blow's Zone N.21 is apparently missing, the sample at 89 cm being put about at the N.20/N.21 boundary and that at 79 cm being Quaternary. Below there is a short sequence of what may represent N.20 in which *G. altispira* is rare and, therefore, may be reworked. A few instances of short overlap of *G. tosaensis* and *G. altispira* in Pacific-Indian Ocean cores will be mentioned later. These cases are suggestive but not conclusive.

PREVIOUS WORK

So much work has been done on the upper Miocene and Pliocene (present interpretation) of the general tropical area of the Pacific and Indian Oceans that a complete resumé will not be given here. Some well-known papers are: Bandy (1963a): Philippines (previously discussed); Boomgaard (1949), Bolli (1966b): Java (In the Bodjonegoro-1 well, Bolli recognized all the Bolli-Bermúdez zones discussed in this paper, except for the *Globoquadrina "altispira altispira"/Globorotalia truncatulinoides* Zone); Huang (1963): Peikang Shelf area of Taiwan; Huang (1966): Sômach Formation, Japan; LeRoy (1941): Borneo, W. Java, W. Sumatra; Todd (1957): Saipan (Todd, 1966, believed that the Donni Sandstone Member of the Tagpochau Formation is Tortonian in age, but I think it is referable to the lower part of Zone N.19 of Banner and Blow); Todd (1964): deep-sea cores off Eniwetok (A re-examination of these cores shows that Core 20 (5 cm), Core 23 (40 cm) and Core 27 (20 cm) are in Banner and Blow's Zone N.19; Core 18 (30 cm) appears to be near the boundary of Zones N.20/N.21, and Core 4 (10-55 cm) is in Zone N.21. This interpretation differs from Todd's mainly in the placement of the Miocene-Pliocene boundary, because she considered the age equivalent of N.19 to be late Miocene); Todd (1966): Guam. Additional papers are mentioned elsewhere in the text and appear in the references.

Although outside the area considered here, the Nobori Formation faunas described by Takayanagi and Saito (1962) are of special interest because they are somewhat tropical in character. According to their table of occurrences, the faunas seem to be mixed (Zones N.19 and N.21). This interpretation is based on the presence of *Globigerina nepenthes* and *Globorotalia tosaensis*, apparently in the same samples. On the basis of the former species, the authors assigned a Tortonian age to the formation, although now it is known that this species ranges much higher, into Zone N. 19. Huang (1966), however, said that Takayanagi and Saito's *G. nepenthes* is a variant of *G. decoraperta*. Thus, if there is mixing, it is much less serious. That there is such mixing partly depends on the development of *G. decoraperta* in the samples. In the Indo-Pacific cores that species seems to have changed into *G. rubescens* below the base of N.21, but the change, a gradual one, is difficult to pinpoint. Before seeing Huang's paper, I had thought that added evidence appeared in these faunas for a lowered range for *Globorotalia tosaensis* in higher latitudes, but such

does not seem to be the case. McTavish correlated the Nobori Formation with the Donni Sandstone of Saipan, which appears to be in Zone N.19. He also believed that the faunas are mixed, containing his "*Globigerina nepenthes* assemblage" (at least pre-Zone N.21, and probably older) and his "*G. dutertrei* assemblage" (Zone N.21, or possibly somewhat older). Thus, he too would now put the formation in the higher position, although his "Helvetian to Pontian-Sarmatian" age does not seem justified by the evidence, even if the Helvetian part is eliminated. It might be well to point out that in any case direct correlation with these stages is impossible because their type sections do not contain planktonic Foraminifera.

The experimental Mohole drilling near Guadalupe Island, Baja California (lat. 28°59'N., long. 117°30'W., 948 m) also contains a semi-tropical Pliocene fauna in core run 8-1, at 80-82 cm (Parker, 1964). A review of this fauna shows that it is early Pliocene in age (lower Zone N.19). Martini and Bramlette (1963) in their study of the nannoplankton of this drilling came to the same conclusion. The Foraminifera include: *Globigerina decoraperta*, *G. quinqueloba*, *Globigerinoides obliquus*, *Globobulimina altispira* (rather atypical, not reported earlier); *G. humerosa* (earlier reported as *G. dutertrei*), *Sphaeroidinella debiscens* (primitive type), and *S. seminulina*. It is interesting to note the presence of *Globigerina falconensis* and *Globorotalia inflata* much lower in the section than they occur in the tropical cores. *Globigerina bulloides* d'Orbigny and *G. pachyderma* Ehrenberg, which do not occur at all in the Pliocene of the tropical cores, also are present. This fauna occurred at about 30 m below the sediment surface.

LOCATION OF CORES AND SAMPLING METHODS

Eighteen cores, as well as one dredge haul and five outcrop samples, have been included in this study. Their locations are listed in Table 1. The cores were taken in an area almost entirely within the tropical belt, extending from lats. 8°36'N. to 24°42'S. and from longs. 62°04'E. to 117°53'W., with depths ranging from 200 to 4,542 m. Lithological descriptions of CAP 2 BP 2 and MSN 126 G are to be found in Riedel and Funnell (1964); those of Indian Ocean cores will be published in the near future (Riedel and Funnell, in preparation). These papers also give photographs of the cores, an explanation of the symbols making up their names, brief descriptions of the contained fossils (nannoplankton, Fora-

minifera, radiolarians) together with age determinations and finally, brief interpretations of the sedimentary conditions which produced them.

The samples were mostly 4 cu cm in size before washing. It is desirable to have larger ones to be sure of finding the rarer fossils, but in working with deep-sea cores it is impossible to obtain large amounts because the demand for material for many types of study is so great. The outer one or two millimeters of sample were removed to eliminate contamination by younger material which may have dragged along the outside as the core barrel penetrated the sea floor. Even so, such material is sometimes present in the washed sample. The samples were usually taken at intervals of about one meter; after inspection additional ones were taken if necessary.

BIOSTRATIGRAPHY OF INDO-PACIFIC CORES

INTRODUCTION

As mentioned earlier, Banner and Blow's (1965b, 1967) zonation (with the possible exception of Zone N.20) is adequate to interpret the fossil sequences found in the cores studied. Although Bolli (1966a) recommended that zones be given index species names, Banner and Blow's index names are not used in this paper but only the original letter number designations. (The names have been included in the "Description of Zones"). I agree with Bolli's point of view, but it seems too soon to give index fossil designations to world-wide zones because there has not been sufficient work done to reconcile the differences between the various suggested zonal schemes. A great deal more data are needed, especially for higher latitudes. When unanimity is reached, it will be appropriate to give species designations; until then names seem to add to the confusion. In small localized areas zones can be safely named with some assurance of permanence.

Deep-sea cores do not provide ideal sections for biostratigraphic work for several reasons. One is the prevalence of calcium carbonate solution which is found much more commonly in the Pacific Ocean than in the Atlantic Ocean, apparently because of the greater depths encountered so widely. Solution breaks down the specimens and acts more readily on some species than others. In general, the globigerinids are more easily dissolved, although *Sphaeroidinella* resists solution. Fortunately many of the species designated by Banner and Blow as indices for their zones are among the last survivors. A second reason is that there is comparatively little dilution

by other types of sediment in the areas where the calcium carbonate components are not dissolved. As a result there is a condensation of the section which leads to mixing at the zonal boundaries and even to the elimination of short-lived zones such as N.20 (if indeed this zone exists). This boundary mixing may be due to burrowing organisms, or it may be that deposition is so slow that a sample can contain material representing parts of two biozones, thus appearing to be mixed. A third difficulty is that in relatively short sequences—10 m at the most—the presence of late Tertiary usually means that a part of the sequence is missing, being overlain by a thin layer of Quaternary. The resulting disconformity can be difficult to detect, especially if it occurs in Zone N.21 or if there has been reworking at the N.21/Quaternary boundary.

Mechanical difficulties leading to faunal mixing have been discussed by Riedel and Funnell (1964). One is the "sucking in" of material when a partially filled core barrel is pulled out of the sediment. In mottled sediments this "sucking in" is revealed by the elongation of the normally rounded or elliptical mottles. Another is contamination of older material by younger because of dragging along the sides of the core as the barrel penetrates the sediments. The material, if still present after careful removal of the outer layer, can often be detected by the difference in preservation of the calcareous tests. Still another is repetition of sequences caused by "bouncing" of the core barrel.

A further source of mixing is brought about if the core penetrates turbidites, as revealed by the presence of graded bedding. Such material is suspect because drastic mixing may result depending upon the source(s) of the material. Burrowing organisms may transfer younger material down into the core. When samples are taken, animal burrows can often be detected and avoided.

Evolutionary sequences are the best and safest means of age determination or correlation. In deep-sea cores such sequences sometimes are reflected in such a short space that evolutionary stages which might be easily detected in well sequences or outcrop sections are found together. This "telescoping" effect means that one can be mistaken in thinking that a given interval truly reflects the time of evolution of a species. This misapprehension is especially possible when one species branched off from another, because afterwards both species, the new and the old, occur simultaneously. A mistaken interpretation is not so likely where one

species changed into another, especially if the two species concerned are not highly variable. An example of the former type of evolution is the development of *Globorotalia tosaensis* from *G. crassaformis*; the impossibility of being sure of the time of this branching evolution as it is reflected in the stratigraphic column at any one locality makes plausible the suggestion that *G. tosaensis* may have appeared earlier at higher latitudes than it did in the tropics or in tropical areas accessible for cooler water. Examples of the second type of evolution are the development of *Sphaeroidinella debiscens* from *S. subdebiscens* and of *Globorotalia truncatulinoides* from *G. tosaensis*. If the species is highly variable, however, the evolution from one species to another can be more difficult to interpret. Such a sequence emphasizes the necessity of studying assemblages rather than specimens, because there are many morphological variations, some of which may persist throughout. An example of an evolution of this type is that of *Globoquadrina acostaensis* to *G. humerosa* to *G. dutertrei*.

The zonal ranges and postulated evolutionary sequences of the species are shown in Text-fig. 2. These ranges are composites of those worked out from the various cores. In addition, Tables 2-4 give species ranges and age determinations for selected cores; age determinations for the remaining cores and other samples are given in Table 1. The relative ages of all the cores are shown in Text-fig. 3. In Tables 2-4 single occurrences and most two-specimen occurrences at either end or outside of a species range have been omitted. An exception to this rule is *Globorotalia margaritae* which occurs rarely in only two cores. By omitting such occurrences, especially at the end of species ranges, it is believed that some reworked specimens have been eliminated. At the beginning of the range, contamination from above by burrowing organisms may be eliminated by this means, unless it was extensive. In addition, some occurrences (outside of known species ranges) due to contamination by dragging (even after removal of the outer layer) are eliminated.

Table 1. Locations and Zonation of Deep-Sea Cores, Fiji Samples, and a Dredge Haul.

The zonation is that of Banner and Blow (1965b). N.16, middle Miocene; N.17, N.18, late Miocene; N.19-N.21, Pliocene. A few significant species occurrences are listed after each determination. Some species are rare, and some samples show much solution of calcium carbonate.

PACIFIC OCEAN

Cores.—

CAP 2 BP 2; 0°47'N., 169°12'E.; 4,270 m; 600 cm long. 577-580 cm, below N.21 (*Globigerinita tota*, *Globigerinoides fistulosus*, *Globorotalia crassaformis*; no *G. tosaensis*); 335-488 cm, N.21 (*Globoquadrina humerosa*, *Globorotalia multicamerata*, *G. tosaensis*).

CAP 38 BP; 14°16'S., 119°11'W.; 3,400 m; 890 cm long. See Table 2.

CHUB 30; 7°17.7'N., 127°24.6'W.; 3,640 m; 52 cm long. 40-52 cm, N.19 *Globoquadrina altispira*, *Pulleniatina spectabilis*, *Sphaeroidinella debiscens*, *S. seminulina*; above mixed Quaternary and older (*Globoquadrina altispira*, *G. conglomerata*, *G. dutertrei*, *Sphaeroidinella seminulina*).

LSDH 78 P; 4°31'S., 168°02'E.; 3,208 m; 526 cm long. See Table 3.

MSN 126 G; 24°41'S., 154°45'W.; 4,542 m (?); 128 cm long. 58-103 cm, N.21 (*Globorotalia tosaensis*); 40-42 cm (and higher), Quaternary (*Globorotalia truncatulinoides*). A sample taken near the bottom of this core was unfossiliferous.

PROA 88 P; 2°56'N., 167°14'E.; 4,428 m; 454 cm long. See Table 3.

RIS 12 G; 8°10'N., 117°53'W.; 3,930 m; 22 cm long. Core-catcher sample, Miocene, possibly N.16 or N.17 (*Globigerina nepenthes*, *Globorotalia mero-tumida*, *Sphaeroidinella seminulina*, *S. subdebiscens*; no *Globorotalia multicamerata*, *G. tumida*, *Pulleniatina*), considerable solution of calcium carbonate. Higher the core shows lithologic evidence of burrowing activity; at 18-19 cm there is a mixed fauna containing *Globoquadrina humerosa* trans *dutertrei*, *Globorotalia tumida*, *Pulleniatina obliquiloculata*; at 11-13 cm there is a sparse fauna (large amount of calcium carbonate solution) which is similar to the core-catcher sample but contains fewer species, including two specimens of *Globorotalia tumida*.

RIS 75 G; 14°01'S., 122°28'W.; 3,790 m; 96 cm long. 87-89 cm, N.21 (possibly older) (*Globigerinoides fistulosus*, 2 specimens of *Globorotalia tosaensis*, *Pulleniatina primalis*); 50-53 cm, Quaternary (*Globorotalia truncatulinoides*).

RIS 77 G; 14°02'S., 128°29'W.; 3,985 m; 67 cm long. 62-64 cm, late Miocene (N.18?) (*Globigerina nepenthes*, *Globorotalia tumida*, *Sphaeroidinella seminulina*, *S. subdebiscens*; no *S. debiscens*); 25-28 cm, Quaternary (very sparse fauna; *Globoquadrina conglomerata*, *Pulleniatina obliquiloculata* ("finalis" type of Banner and Blow, 1967), *Sphaeroidinella debiscens*).

RIS 82 G; 14°03'S., 139°35'W.; 3,900 m; 127 cm long. 120-122 cm, Pliocene (may be some mixing in this sample; *Globigerinoides fistulosus*, *Pulleniatina primalis*, *P. obliquiloculata*, *Sphaeroidinella debiscens*); 56-100 cm, lower N.19 (*Globigerina nepenthes*, *Sphaeroidinella debiscens*); 26-29 cm, Quaternary (only one specimen of *Globorotalia truncatulinoides*, but *Globanomalina* (?) *pumilio* and *Globigerina digitata* are present).

RIS 84 G; 15°15'S., 142°27'W.; 3,675 m; 49 cm long. 42-44 cm, mixed Eocene, Pliocene, and Quaternary. The bulk of the sample is Pliocene (*Globigerinoides fistulosus*, *Globoquadrina altispira*, *Globorotalia multicamerata*, *Sphaeroidinella debiscens*, *S. seminulina*).

SDSE 58; 6°44'N., 129°28'W.; 4,440 m; 10 m long (approximate). 760-986 cm, N.21 (*Globorotalia multicamerata*, *G. tosaensis* (at 760 cm only), *Pulleniatina obliquiloculata*); 593-595 cm, Quaternary (modern *Globoquadrina dutertrei* assemblage).

Dredge Sample.—

CAP Alexa-Penguin Bank, Dredge No. 2; 11°5'S., 175°10'E. (approximate position); 2,560 m. Mixed N.17 and Quaternary (*Globigerina nepenthes*, *Globigerina rubescens* (red), *Globigerinoides tenellus*, *Globorotalia merotumida*, primitive *G. tumida* (not the typical form found in N.18), *Sphaeroidinella subdehiscens*).

Outcrop Samples.—

Fiji: Suva Marl from Viti Levu (Coll. by H. A. Lowenstam)

F1; roadcut on Princess Road, N. edge of Nainetungatu. Late Miocene (N.18) (*Globigerina nepenthes*, *Globoquadrina altispira*, *Globorotalia cibaoensis*, *G. multicamerata*, *G. tumida*, *Sphaeroidinella seminulina*, *S. subdehiscens*; no *S. dehiscens*).

F2a; base of bluff behind Carlton Brewery, Suva. Late Miocene (N.17) (*Globoquadrina acostaensis*, *Globorotalia cibaoensis*, *G. merotumida*, *Sphaeroidinella seminulina*, *S. subdehiscens*; no *Globorotalia tumida*).

F3b; bluff at Shell Oil depot, Suva. Late Miocene (N.18) (*Globigerina nepenthes*, *Globorotalia margaritae*, *G. multicamerata*, *G. tumida*, *Pulleniatina primalis*, *Sphaeroidinella seminulina*, *S. subdehiscens*; no *S. dehiscens*).

F13b; base of road cut on E. bank of Waimana Creek, 1 mile SSW. of Ndevuilevu. Early Pliocene (basal N.19) (*Globigerina nepenthes* (?rare), *Globigerinoides fistulosus*, *Globoquadrina humerosa*, *Globorotalia crassaformis*, *G. multicamerata*, *G. tumida*, *Sphaeroidinella dehiscens* (primitive)).

F35; Navua River bluff, 2.7 miles WSW. of Waimbongi. Late Miocene (N.18) (*Globigerina nepenthes*, *Globoquadrina humerosa*, *Globorotalia multicamerata*, *G. tumida* (rare), *Pulleniatina primalis*, *Sphaeroidinella seminulina*, *S. subdehiscens*).

These samples from the oldest to the youngest are: F2a, F35, F3b, F1 (F1 and F3b appear to be the same age but F1 is stratigraphically 100 ft. above F3b), F13b

INDIAN OCEAN

Cores.—

DODO 57 P; 15°40'S., 112°44'E.; 3,660 m; 115 m long. See Table 4.

DODO 117 P; 18°21'S., 62°04'E.; 3,398 m; 456 cm long. This core was "sucked in" below 290 cm. See Table 4.

DODO 141 G; 24°42'S., 73°05'E., 3,600 m; 122 cm long. See Table 4.

LSDA SCS 5G; 8°36'N., 115°29'E.; 2,200 m; 170 cm long. 131-161 cm, lower N.21 (*Globigerina rubescens* (white), *Globigerinoides bollii*, *G. obliquus*, *Globoquadrina humerosa*, *Globorotalia multicamerata*, *G. tosaensis*); 109-111 cm, Quaternary, some reworked Pliocene (*Globanomalina* (?) *pumilio*, *Globigerina rubescens* (red), *Globoquadrina dutertrei*, *Globorotalia multicamerata* (rare), *G. truncatulinoides*)

LSDA 101 G; 2°41'S., 73°12'E.; 2,960 m; 53 cm long. This core contains a mixed fauna which apparently contains elements of Zone N.18 mixed with Pliocene (or Quaternary?), varying at different levels (*Globigerina nepenthes*, *Globoquadrina acostaensis*, *G. altispira*, *G. humerosa*, *Globorotalia tosaensis*,

G. tumida, *Pulleniatina primalis*, *Sphaeroidinella seminulina*; not all of these species occur in every sample); the fauna at 36-38 cm appears to consist of unmixed Zone N.17 or N.18 fossils (*Globigerina nepenthes*, *Globoquadrina humerosa*, *Globorotalia cibaoensis*, *Pulleniatina primalis*, *Sphaeroidinella subdehiscens*; no *Globorotalia* of the *G. tumida* group).

MSN 56 P; 23°56'S., 73°53'E.; 3,700 m; 684 cm long. This core was "sucked in" below 250 cm. 226-228 cm, N. 19 (*Globigerina nepenthes*, *Globoquadrina altispira*, *Globorotalia multicamerata*, *Sphaeroidinella dehiscens*), 129-202 cm, N.19 or N.20 (*Globigerinoides fistulosus* (in part), *Globorotalia multicamerata* (in part); no *Globoquadrina altispira*, *Pulleniatina*); 79-102 cm, N. 21 (*Globorotalia tosaensis*); 51-53 cm (and higher), Quaternary (*Globorotalia truncatulinoides*).

Several of the cores show excellent sequences for one or two zones and only three cores show more than two zones. The most extensive stratigraphic coverage is found in CAP 38 BP (Table 2), which extends from upper middle Miocene (N.17) to Quaternary apparently without a break. The considerable amount of solution of calcium carbonate in this core probably was the concentrating agent, at least in part. The result is that species which normally show more or less extended overlaps elsewhere may show short ones in the cores, or species which do not overlap in land sections may do so in the telescoped core sections.

CAP 38 BP, after collection, was stored in sections about 70 cm in length. It became apparent after study that three of the sections had been stored in reverse. The reversal of the lowest, 555-624 cm, was detected by the coccolith succession and color matching (M. N. Bramlette, W. R. Riedel, personal communications). The second, 415-485 cm, was detected by the foraminiferal successions and comparison of the foraminiferal faunas in the end samples with those in the end samples of adjacent sections. The discoaster abundances corroborated this reversal, discoasters being abundant at 485-487 cm (end of adjacent section) and 483-485 cm (end of *reversed* section) and rare at 415-417 cm (end of *reversed* section) and 413-415 cm (end of adjacent section). The third reversal, 345-415 cm, was detected by both the foraminiferal faunas and color matching. Table 2 gives data for the end samples of the last two sections, as well as for those of the adjacent sections. The Foraminifera in the end samples of all sections were examined to make sure that the core was otherwise properly stored. Similar checks of lithology and coccolith succession have been made also.

In addition to the stratigraphic section found in CAP 38 BP (Zones N.17-Quaternary; Zone N.20 is not present either because of its brevity or nonexistence), Zone N.16 (middle Miocene) appears in PROA 88 P

	PROA 88P, 2°56'N 167°14'E, 4428m							LSDH 78 P, 4°31'S 168°02'E, 3208m													
ZONE (Banner & Blow, 1965b, 1967)	N.16				QUAT.			N.18			N.19 (lower)					N.19-QUAT.					
DEPTH IN CORE (cm)	449-451	278-280	200-202	170-172	130-132	96-98	25-27	516-519	499-502	470-472	450-453	399-402	299-302	216-218	150-153	100-102	85-87	74-77	30-32	19-22	0-2
<i>Globigerinoides sacculifer</i> (prim.)	•	•	•	•	•																
<i>Globoquadrina continuosa</i>	•																				
<i>Globorotalia merotumida</i>	•	•	•	•	•																
<i>Globoquadrina acostaensis</i>				•	•																
<i>Orbulina</i> sp. (bilobate)	•																				
<i>Sphaeroidinella dehiscent</i>							•	•												•	•
<i>Pulleniatina spectabilis</i> (prim.)								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globoquadrina pseudofoliata</i>																				•	
<i>Globigerina nepenthes</i>			•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Pulleniatina spectabilis</i> (typical)																•	•	•	•	•	•
<i>Pulleniatina obliquiloculata</i>							•	•								•	•	•	•	•	•
<i>Globigerina praedigitata</i>								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerinoides ruber</i> (and vars.)																					
<i>Globigerina calida</i> (primitive)									•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerina decaraperta</i>	•	•						•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerinoides bollii</i>	•	•						•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerinoides obliquus</i>	•		•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globoquadrina humerosa</i>								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globoquadrina venezuelana</i>	•	•	•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globorotalia margaritae</i>																					
<i>Globorotalia multicamerata</i>								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Pulleniatina primalis</i>								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Sphaeroidinella subdehiscent</i>	•	•	•	•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerina digitata</i>																					
<i>Globigerinita iota</i>						•	•													•	•
<i>Globigerinoides fistulosus</i>																				•	•
<i>Globoquadrina conglomerata</i>																					•
<i>Globorotalia crassaformis</i>							•	•													•
<i>Globorotalia losaensis</i>																					•
<i>Globorotalia truncatulinoides</i>							•														•
<i>Globigerinoides sacculifer</i> (typ.)								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globoquadrina altispira</i>	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Sphaeroidinella seminulina</i>	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerina calida</i> (typical)																					
<i>Globigerinoides ruber</i> (variant)																					
<i>Globigerinoides sacculifer</i> (mod.)							•	•													•
<i>Globoquadrina dutertrei</i>							•	•													•
<i>Globorotalia anfracta</i>																					•
<i>Globorotalia fimbriata</i>																					•
<i>Globanomalina</i> (?) <i>pumilio</i>																					•
<i>Globigerina rubescens</i>							•														•
<i>Globigerinita adamsi</i>																					•
<i>Globigerinoides tenellus</i>																					•
<i>Globorotalia crassula</i>																					•
<i>Candeina nitida</i>																					•
<i>Globigerina</i> cf. <i>G. quinqueloba</i>							•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerinita siphonifera</i>	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerinita glutinata</i>	•							•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerinita uvula</i>	•							•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globigerinoides conglobatus</i>							•														•
<i>Globoquadrina hexagona</i>								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globorotalia cultrata</i>	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globorotalia scitula</i>								•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Globorotalia tumida</i>							•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Hastigerina pelagica</i>																					•
<i>Orbulina universa</i>	•	•	•					•	•	•	•	•	•	•	•	•	•	•	•	•	•
<i>Turborotalia humilis</i>							•	•													•

Table 3. Species Ranges in PROA 88 P and LSDH 78 P, with Age Determinations and Zonation.

	DODO 57P, 15°40'S 112°44'E, 3660m					DODO 117 P, 18°21'S 62°04'E, 3398m					DODO 141G, 24°42'S 73°05'E, 3600m				
ZONE (Banner & Blow, 1965b, 1967)	N.19		N.21		Q	N.20		N.21		Q	N.21		QUAT.		
DEPTH IN CORE (cm)	core catcher				0-2					0-2					
	109-111	99-96	79-81	61-62	40-42	20-22									
<i>Globigerina nepenthes</i>	•	•													
<i>Sphaeroidinella subdehiscens</i>	•	•													
<i>Sphaeroidinella seminulina</i>	•		•												
<i>Pulleniatina obliquiloculata</i>			•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globoquadrina altispira</i>	•	•	•	•											
<i>Globigerinoides fistulosus</i> (prim.)															
<i>Globigerinoides ruber</i> (variant)															
<i>Globigerinoides fistulosus</i> (typ.)				•	•	•	•	•	•	•	•	•	•	•	
<i>Globorotalia hirsuta</i>															
<i>Globorotalia multicamerata</i>	•			•	•										
<i>Globigerina decoraperta</i>				•	•										
<i>Globigerina rubescens</i>															
<i>Globanomalina praepumilio</i>															
<i>Globigerina falconensis</i>															
<i>Globigerinoides sacculifer</i> (typ.)	•	•	•	•											
<i>Globigerinita iota</i>															
<i>Globigerinoides sacculifer</i> (mod.)															
<i>Globigerina calida</i> (primitive)	•		•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globorotalia tosaensis</i>															
<i>Globoquadrina venezuelana</i>	•	•	•	•											
<i>Globigerina calida</i> (modern)															
<i>Globorotalia anfracta</i>															
<i>Globorotalia inflata</i> (variant)															
<i>Globoquadrina pseudofoliata</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Pulleniatina primalis</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globigerinoides bollii</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globigerinoides obliquus</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globorotalia crassula</i>															
<i>Globorotalia fimbriata</i>															
<i>Globoquadrina humerosa</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globoquadrina dutertrei</i>															
<i>Globorotalia inflata</i>				•	•										
<i>Globorotalia truncatulinoides</i>															
<i>Globigerina praedigitata</i>	•		•												
<i>Globigerina digitata</i>															
<i>Globanomalina</i> (?) <i>pumilio</i>															
<i>Globigerinella adamsi</i>															
<i>Globigerinoides tenellus</i>															
<i>Candeina nitida</i>															
<i>Globigerina</i> cf. <i>G. quinqueloba</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globigerinella siphonifera</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globigerinita glutinata</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globigerinita uvula</i>															
<i>Globigerinoides conglobatus</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globigerinoides ruber</i> (and vars)															
<i>Globoquadrina hexagona</i>		•													
<i>Globorotalia crassiformis</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globorotalia cultrata</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Globorotalia scitula</i>				•	•										
<i>Globorotalia tumida</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Hastigerina pelagica</i>															
<i>Orbulina universa</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Sphaeroidinella dehiscens</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
<i>Turborotalita humilis</i>	•	•	•	•	•	•	•	•	•	•	•	•	•	•	

Table 4. Species Ranges in DODO 57 P, DODO 117 P and DODO 141 G, with Age Determinations and Zonation. DODO 117 P was "sucked in" below 290 cm.

* This occurrence is probably due to contamination.

(Table 3) (included here to show origin of some N.17 fossils) ; Zone N.18 appears also in LSDH 78 P (Table 3) ; Zone N.19 is also well developed in LSDH 78 P (Table 3) and to a lesser extent in DODO 57 P (Table 4) ; Zone N.20 is apparently present in DODO 117 P (Table 4) ; Zone N.21 is also present in DODO 57 P (Table 4), DODO 117 P (Table 4) ; the four specimens of *Globorotalia truncatulinoides* at 180-182 cm are believed to be contaminants because of their fresh appearance and unusual occurrence ; one specimen was found in the sample at 200-202 cm), and DODO 141 G (Table 4). Some of these zones also are represented in the other cores as listed in Table 1 (see also Text-fig. 3) ; some of these cores, however, contained mixed faunas.

Evolutionary sequences are well shown in the cores. Spectacular examples are the development and occurrence of *Globigerinoides fistulosus* in DODO 117 P, although the first appearance of primitive *G. fistulosus* may be at an earlier time than is represented in this core, and the evolution of *Sphaeroidinella dehiscens* from *S. subdehiscens* in LSDH 78 P and CAP 38 BP (seen also in the Lamont core V3-153 from the Blake Plateau). Discussion of other evolutionary sequences are given in the section on systematics, as well as in the description of the zones that follows.

DESCRIPTION OF ZONES

Zone N.16.—("*Globorotalia* (*Turborotalia*) *acostaensis* (s.s.)—*G.* (*G.*) *merotumida* partial range zone" of Banner and Blow, 1965b). This zone is considered to be late middle Miocene in age, but is included here to show the development of some of the Zone N.17 forms. It is represented in only one core, and the data, therefore, are probably incomplete. It is identified by the simultaneous occurrences of *Globorotalia merotumida* and *Globoquadrina acostaensis* and is the only zone in which *G. continuosa* appears in this region.

Zone N.17.—("*Globorotalia* (*G.*) *tumida plesiotumida* consecutive-range-zone" of Banner and Blow, 1965b). This zone is represented in one core, as well as in one Fiji sample (F2a) and in a dredge haul from Alexa-Penguin Bank. Its base is defined by the first occurrence of "*Globorotalia* (*G.*) *tumida plesiotumida*". Although observed in Lamont core V3-153 (Atlantic, Blake Plateau), this form cannot be positively identified in the Pacific-Indian Ocean region material studied, although questionable specimens occur at 860-862 cm and 829-831 cm in CAP

38 BP (see also discussion of *G. tumida*). *Pulleniatina primalis* first appeared in this zone and *Globorotalia multicamerata*, developed presumably from some species of the *G. cultrata* group. Because Zone N.16 is so poorly represented in the cores, it is not possible to be certain of some of the evolutions or starting ranges. *Globigerina praedigitata* is first seen in Zone N.17 but its downward range is uncertain. The following species also appeared, although some are known to range lower elsewhere: *Candeina nitida*, *Globigerina* cf. *G. quinqueloba*, *Globigerinoides conglobatus*, *G. ruber*, *Globoquadrina hexagona*, *Globorotalia scitula*, *Hastigerina pelagica*, *Turborotalita humilis*.

Zone N.18.—("Globoquadrina (*G.*) *tumida tumida*—*Sphaeroidinella subdehiscens* partial-range-zone" of Banner and Blow, 1965b). Banner and Blow defined the base of this zone by the first occurrence of typical *Globorotalia tumida*, and the zone is well shown in some of the present cores. *Globoquadrina humerosa* apparently developed from *G. acostaensis* in the lower part of this zone, although Banner and Blow (1967) placed this evolution at the end of N.16. *Globigerina calida* (primitive form) first occurs just below the base but so rarely that it is uncertain if it might not have first developed lower down. *Globorotalia margaritae* first occurs high up in this zone but is so rare in the cores that the range shown is not dependable, nor is its source indicated. Typical *Globigerinoides sacculifer* developed from the primitive form near the base. *Globoquadrina dehiscens* disappeared in the lower part and *Orbulina* sp. (bilobate) at the top. In addition to the cores, excellent material of N.18 age occurs in the Suva Formation of Fiji (F35, F1, F3b).

Zone N.19.—("Sphaeroidinella *dehiscens* (s.s.)/*Globoquadrina altispira* (s.s.) concurrent-range-zone" of Banner and Blow, 1965b). The base of this zone is marked by the first occurrence of *Sphaeroidinella dehiscens*. The development of this species from *S. subdehiscens* is an excellent correlation point because in the core sequences the former species is apparently replaced by the latter quickly. The base of Zone N.19 is placed at the point where there is good evidence that *S. dehiscens* had developed. Questionable specimens or the occurrence of one or two specimens are considered to be insufficient to mark this point in the cores unless the number of occurrences rapidly increases in the following core sequences. *Globorotalia crassula* developed from *G. cibaoensis* in this zone. *G. crassaformis* first occurs at the base but it is possible that it appeared earlier at higher latitudes, especially as its derivation is not indicated in this area.

Globoquadrina pseudofoliata branched off from *G. venezuelana*, typical *Pulleniatina spectabilis* from *P. primalis* (transitional specimens occur below the base of the zone) and somewhat higher *P. obliquiloculata* appeared, probably also derived from that species. At about the same time, *Globigerinoides fistulosus* developed from *G. sacculifer* (typical form). *Globigerina nepenthes* disappeared in the lower part of the zone. *Globigerinita iota* appeared near the top of this zone, developed apparently from *G. glutinata*, although this evolution is not clearly demonstrated.

Zone N.20.—("*Globorotalia* (*G.*) *multicamerata*-*Pulleniatina obliquiloculata* (*s.s.*) partial-range-zone" of Banner and Blow, 1965b). This zone is defined by the concurrent ranges of occurrence of *Globorotalia multicamerata* and their "*Pulleniatina obliquiloculata* (*s.s.*)" above the extinction of *Globoquadrina altispira* and below the appearance of *Globorotalia tosaensis*, which, by definition, marks the base of Zone N.21. The best core showing such an occurrence of the nominate species is DODO 117 P. In another core, MSN 56 P, the sample at 129-131 cm appears to represent the zone, but no *Pulleniatina* occur. *Globorotalia multicamerata* occurs but *Globoquadrina altispira* does not. The sample has undergone considerable solution of calcium carbonate. In both CAP 38 BP and DODO 57 P, the final occurrence of *Globoquadrina altispira* is in the same sample as the first occurrence of *Globorotalia tosaensis*. Thus, Zone N.20, as defined, is absent from both the cores. Blow (personal communication) believes that the presence of *G. altispira* so high is due to reworking, but at 491-493 cm in CAP 38 BP this species is relatively common. Three specimens were found at 61-62 cm in DODO 57 P. Specimens referable to Banner and Blow's (1967) "*Pulleniatina obliquiloculata obliquiloculata*" (= *P. obliquiloculata* (*s.s.*) of Banner and Blow (1965b); included in *P. obliquiloculata* here) occur in CAP 38 BP and DODO 57 P in Zone N.19.

When Zone N.20 is referred to in the systematic descriptions, it specifically refers to the section in DODO 117 P, which apparently represents this zone. *G. ruber* "var." appeared in this zone. *Globigerina falconensis* appeared near the top of the zone in DODO 117 P, somewhat higher in a few other cores. *Globorotalia hirsuta* first appeared near the top of this zone, possibly derived from *G. margaritae*, although this evolution is not clearly demonstrated but only suggested in the cores. *Globanomalina praepumilio* appeared at the same time; its derivation is not known, and it may have developed earlier. Small species like this one

were eliminated from many cores, apparently by solution. *Globigerina rubescens* gradually evolved from *G. decoraperta* in this zone.

Zone N.21.—("Globo*rotalia* (*G.*) *tosaensis* consecutive-range-zone" of Banner and Blow, 1965b). Banner and Blow defined the base of this zone by the first occurrence of *Globo*rotalia* tosaensis* which apparently evolved from *G. crassaformis* at the base of the zone. The possibility that *G. tosaensis* may have appeared lower in the section at higher latitudes was mentioned earlier, in the introduction to this section. Evidence against this theory is that in some cores (for example, DODO 57 P, at 61-62 cm; DODO 117 P, at 200-202 and 180-182 cm) the evolutionary sequence of *G. crassaformis* to *G. tosaensis* looks very convincing. However, the danger of misinterpreting such an evolution has already been discussed. It might be argued that a possibly high first appearance of *G. tosaensis* in Zone N.21 in the tropics is evidence of lowered water temperature in this area at the time represented which allowed this species to occur more commonly than its descendant, *G. truncatulinoides*, does at the present time. Additional evidence for this point of view is that in DODO 117 P *G. inflata* first appeared in Zone N.21. It also occurs in Zone N.21 in some other cores in which N.21 is the lowest zone represented. Exceptions are occurrences in MSN 56 P at 226-228 cm (Zone N.19) and 129-131 cm (Zone N.19 or N.20). *G. inflata* is found throughout the Italian Pliocene and possibly in the upper Miocene as well. It marks the Pliocene boundary in Australia and New Zealand, although the correlation of this boundary with the one presently used is not certain. *G. inflata* is rare, if present at all, in modern tropical faunas of the Indo-Pacific region. The solution of the problem of the downward extension of the range of *G. tosaensis* must await further data.

Zone N.21 is marked by the gradual change of several species into morphologically different ones: *Globoquadrina humerosa* into *G. dutertrei* (which is not completed until Zone N.22), phylogenetically primitive *Globigerina calida* into the typical form (but not perhaps as evolute as the modern form of the species), *Globoquadrina venezuelana* into *G. conglomerata* (also not completed until Zone N.22). Near the base of this zone typical *Globigerinoides sacculifer* changed to a form much like the modern one. *Globo*rotalia* anfracta* appeared at the base of this zone, but its origin is unknown. The following species disappeared in the lower part of this zone: *Globigerinoides bollii*, *G. obliquus*, *Globo*rotalia* multicamerata*, *Pul-*leniatina* primalis*, *P. spectabilis*, *Sphaeroidinella seminulina* (Banner and

Blow, 1967, believed this species became extinct at the top of Zone N.19), and, apparently, *Globoquadrina altispira*.

Zone N.22.—("Globorotalia (G.) *truncatulinoides* partial-range-zone" of Banner and Blow, 1965b). Banner and Blow defined the base of this zone by the first occurrence of *Globorotalia truncatulinoides*. In the cores *Globigerinoides fistulosus* apparently disappeared at the base, but there is some doubt because an upper Quaternary fauna may lie on a Zone N.21 section, and this absence of lower Quaternary, if it occurs, is impossible to detect in this area at the present state of our knowledge. Somewhat higher, *Globoquadrina pseudofoliata* became extinct. In this zone *Globoquadrina dutertrei* reached its typical modern variable assemblage, as did *G. conglomerata*, although both species were partially developed in Zone N.21; *Globigerinoides tenellus* first occurs at the base (?), developed perhaps from *Globigerina rubescens*; typical *G. digitata* developed from *G. praedigitata* and *Globanomalina* (?) *pumilio* from its ancestral form (?), *G. praepumilio*. In the course of the Quaternary some other changes took place and typical modern forms of some species developed, but these evolutionary sequences have not yet been worked out in core sections of this region. *Globigerinella adamsi* appears to be a modern form developed from *G. siphonifera*.

ECOLOGICAL OBSERVATIONS

Most planktonic species in the cores, throughout the upper Miocene and lower part of the Pliocene up to Zone N.21, appear to be those typical of the tropics, although not necessarily confined to this area. *Globorotalia margaritae*, described from the tropics (Venezuela) and later reported by Bolli (1966b) from the tropical island of Java, nevertheless may not be a typical tropical species. It is rare in the cores. This scarcity may be due to solution of the thin-walled test or because the species is more typically a temperate one.

Near the base of Zone N.21 a few species appeared which are more common in temperate waters of the present day: *Globigerina falconensis*, *Globorotalia inflata* (earlier occurrences in MSN 56 P), *G. hirsuta*, and *G. tosaensis*. The last species has already been discussed. *G. hirsuta* may have appeared at this time as the result of evolutionary development. Like its possible parent, *G. margaritae*, one cannot be sure whether it is a tropical or temperate species because it has a scattered distribution in the surface sediments of the Pacific, but there are some indications that it may

indeed prefer the temperate waters. This species occurs only in Indian Ocean cores whereas *G. margaritae* was only observed rarely in Pacific cores. However, *G. hirsuta* is relatively more abundant when it occurs. In the Indian Ocean surface sediments the species is absent from the tropical zone, according to Beliaeva (1964), and I have observed it only in surface sediments south of about lat. 25°S. in that ocean.

G. inflata is known to occur throughout the Pliocene in the Italian section, and I have observed it in the lower Pliocene in the beds of the type Tabianian (lowermost Pliocene stage of Italy).

G. truncatulinoides developed at the base of the Quaternary and in this part of the section is common in the cores. In CAP 38 BP, which contains the greatest thickness of Quaternary, the species remains relatively common to about 343 cm. In the next higher sample studied, at 275 cm, it is rare, and becomes increasingly so going up the section to 138 cm, at which point it disappears. This gradual disappearance is not noted in Table 2 but was observed by the study of several samples not listed in this table. It is believed that this disappearance indicates decreasing glaciation, but at this time it is not known which glacial period is represented or whether or not there is a disconformity in the Quaternary part of the core. Further study of the Pleistocene section of this core is planned.

Globigerina falconensis first evolved in the Miocene but appeared in the cores at varying positions, from near the top of Zone N.20 up to the basal part of the Quaternary. Although seen rarely in the surface sediments of the tropical Pacific Ocean and Indian Ocean, it only becomes relatively common south of about lat. 25°S.

The appearance of these various species in Zone N.21 suggests that there was a cooling of the tropical water at the time represented. This cooling is certainly to be expected. In fact, there is every indication that glaciation probably was going on in some parts of the world during this part of the Pliocene and perhaps even earlier. This is evidenced by the occurrence of alluvial terrace formations in the Gulf Coast area (Akers, 1965) at a time that apparently preceded that represented by the Pliocene-Pleistocene boundary in the Italian section, according to our present knowledge.

SYSTEMATIC DESCRIPTIONS

INTRODUCTION

The philosophy underlying the present classification is the same as that of a previous one on Recent planktonic Foraminifera (Parker, 1962).

The importance of forming a natural classification is even greater now than it was five years ago, as the proliferation of species and genera in the literature continues. To achieve an entirely natural classification is impossible because of lack of data. Lack of data and detailed study of the planktonic Foraminifera of only parts of the stratigraphic column mean that some genera must include a wide range of forms which very likely can be subdivided when the lineages are better understood. These new genera of necessity will have different criteria from those used now. Evolutionary lineages, as mentioned earlier, are the best means we have for long-range correlation. I agree with Newell (1956) who said: "... I do not believe that it can be demonstrated that there is any taxonomic scheme superior to phylogenetic classification for the practical needs of stratigraphy." Perhaps had we built up a classification of horizontal polyphyletic genera with stratigraphic significance their retention would be justified. Such genera do exist in the classification of planktonic Foraminifera but not in the late Miocene-Pliocene part of the section, where the only genus having a narrow range, *Pulleniatina*, is not polyphyletic. Polyphyletic genera in this part of the section include: *Globigerinoides*, *Globoquadrina* s.s. and *Globorotalia* s.s.

Globorotalia s.s. has already been expanded by workers to include unkeeled forms, often called *Turborotalia*, either generically or subgenerically. Because *Turborotalia* is also polyphyletic it is not used here, but the genus *Globorotalia* is expanded to include some of the forms referred by many workers to this genus, including the type species *G. centralis* (Cushman and Bermúdez). The excluded species are those comprising "*Globorotalia* group 3" of Parker (1962) which are unrelated to the globorotaliids, as shown by the entirely different character of their walls. There are various lineages of *Globorotalia* [at least of Neogene species including the type species *Globorotalia tumida* (Brady)] which have evolved from unkeeled species into keeled ones. The evolution of *Globorotalia crassaformis* (unkeeled) to *G. tosaensis* (unkeeled) to *G. truncatulinoides* (keeled) is an example occurring in the Pliocene.

The genus *Globoquadrina* s.l. can be subdivided logically only by studying the various lineages presently included in that genus. Related genera include "*Globorotaloides*" (type species *G. variabilis* Bolli), *Subbotina* (type species *Globigerina triloculinoides* Plummer), and *Catapsydrax* (type species *Globigerina dissimilis* Cushman and Bermúdez). Of these genera, "*Globorotaloides*" as interpreted by many authors is a polyphyletic

genus (others frequently refer some of the same species to *Globorotalia* or *Turborotalia*). ..*Globorotaloides* s.s. is considered to be synonymus with *Globoquadrina*, as previously concluded (Parker, 1962). In the present study, in order to eliminate some of the polyphyletic aspects of *Globoquadrina* s.s., both *Globorotalia acostaensis* and *G. continuosa* are referred to *Globoquadrina*, the latter somewhat tentatively. The evolution of *G. acostaensis* to *G. humerosa* to *G. dutertrei* occurred in the late Miocene and Pliocene. Tropical *G. dutertrei* appears to be typical *Globoquadrina* s.s. with open umbilicus, interiomarginal aperture and umbilical teeth. Banner and Blow (1967) postulated the development of *Pulleniatina* from *Globoquadrina acostaensis* (referred by them to "*Globorotalia* (*Turborotalia*)"). It seems reasonable to suppose that this genus is related to the pitted-wall forms because a pitted wall is often seen, especially in juvenile specimens. As a result of his wall studies, Lipps (1966) believed this genus to be an offshoot of *Globigerina*, but he did not state from which species it may have evolved (see also discussions under Catapsydracidae and *Pulleniatina*).

Globigerinoides is retained for the present because the various lineages cannot be unraveled without a detailed study of the early Tertiary species, and it is probable that no single genus can be expanded to include all the species. For example, Bé (1965) demonstrated the probable relationship of *G. sacculifer* and its relatives to *Sphaeroidinella*. He attempted to show that *G. sacculifer* and *S. debiscens* are conspecific, but the Tertiary history of the various species of *Sphaeroidinella* does not bear this out and, at best, a relationship between the two species has been convincingly demonstrated. It is possible that *G. sacculifer* and its relatives, including *G. trilobus* and/or *G. quadrilobatus*, should be referred to the genus *Sphaeroidinella*. Hofker (1959) may be correct, however, in placing most species of *Globigerinoides* in *Globigerina*.

No subspecies have been included in the present study. Contrary to the views expressed previously (Parker, 1962, p. 229), it now seems preferable to reserve the subspecific category for "chrono-subspecies" which can be designated as our knowledge of geographic variation increases. Differences between Atlantic fossil species and Pacific fossil species of any given age also could be so designated. The use of subspecies to mark variations in assemblages is unrealistic and a waste of an excellent method to convey information of stratigraphic or ecologic value. When one variable plexus changes into another which contains many of the same varia-

tions but also added different ones, it is more appropriate to recognize this change specifically as a whole, rather than to add new subspecies to the list to show the added variations. Such species are easy to recognize but necessitate the study of assemblages rather than individuals. Variation of this type is seen in *Globoquadrina dutertrei*. The species *acostaensis* developed, probably in Tortonian time (Zone N.16 of Banner and Blow, 1965b); in the basal part of Zone N.18 it began to vary considerably to form the species *G. humerosa*, (there is some evidence, however, that these two species remained distinct for a short time, and are so plotted in Table 2); then, during Zone N.21, further variation and change produced the species *G. dutertrei*. The last species includes variations similar to some in the previous species, but taken as a whole the assemblages look different. There is no doubt that *G. dutertrei* can be subdivided geographically into subspecies. The high-latitude form, for example, is unlike the tropical one of the Pacific in lacking umbilical teeth (so far as I have been able to determine) and in having a more trochoid test as opposed to the flattened one of the tropical Pacific, which might be referred to the subspecies *G. dutertrei subcretacea* Lomnicki. A further danger of subdivision within a species assemblage is the change that sometimes occurs in a worker's concept of the variant form, resulting in similar variants being referred to different subspecies.

The figured types are deposited in the U. S. National Museum, Washington, D. C. Some of the species have been fully illustrated previously (Parker, 1962), and reference is given to these figures to amplify those given here so that the species variations can be better understood.

DESCRIPTIONS

Family **CANDEINIDAE** Cushman, 1927

(Nom. trans1. ex subfamily Candeininae Cushman, 1927)

In revising the Globigerinacea according to test wall structure Lipps (1966) placed the subfamily Candeininae in the family Globorotaliidae. This classification does not seem justified any more than would the combining of the Hantkeninidae with the Globorotaliidae, which according to Lipps also have the same basic wall structure. This subfamily is, therefore, raised to family status here. The only characteristic in common between the Globorotaliidae and the species here included in the Candeinidae is the trochoid test. The test walls of the two groups differ in that the globo-

rotaliids often develop short, stubby, secondary spines whereas the candeinids sometimes develop short, fine secondary spines; neither group has the long spines characteristic of living globigerinids.

The combining of *Candeina* and *Globigerinita* in one group, as Lipps did, is reasonable because juvenile specimens of *C. nitida* (the type species of *Candeina*) are similar to *Globigerinita*, more so than the adults, and *Candeina* probably developed from that genus. Berger (1966) found that living *Globigerinita glutinata* and *G. iota* both stained a deep violet color with Methylene Blue. The only other species that he observed to stain the same color is *Candeina nitida* (Berger, personal communication). The implications of this identical staining are not known but perhaps it indicates a physiological affinity.

Lipps (1966) included *Eoglobigerina* in the subfamily Candeininae, but according to Berggren (1962) the type species [*Globigerina* (*Eoglobigerina*) *eobulloides*] is a synonym of "*Globigerina*" *pseudobulloides* Plummer. In fact the descriptive word for the test wall, translated by Berggren as "microperforate", might be better translated as "microreticulate" (literally "microcellular"). The "*G.*" *pseudobulloides* complex appears to be ancestral to *Globoquadrina* s.l. (and *Catapsydrax*). "*Globorotalia*" *pumilio*, referred by Lipps to *Eoglobigerina*, is here referred tentatively to *Globanomalina*.

Turborotalita humilis, concerning whose antecedents nothing is known, is included in the Candeinidae with some doubt. It may be more closely related to the globorotaliids. This species somewhat resembles the species referred here to *Globigerinita* but does not appear to be closely related to them. "*Eoglobigerina*" *operta* Lipps may be referable to *Turborotalita* also, although in some ways it seems to be more closely akin to *Globigerinita*. So little work has been done on the small species of the Miocene that more data are needed before these species and other small forms can be accurately classified according to their phylogeny.

Genus **CANDEINA** d'Orbigny, 1839

Candeina nitida d'Orbigny

Pl. 17, figs. 1, 2

Candeina nitida d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminifères," p. 108, pl. 2, figs. 27, 28.

Candeina nitida d'Orbigny, Parker, 1962, Micropaleont., vol. 2, No. 2, p. 253, pl. 8, figs. 27-30.

This species occurs throughout the core sequences from Zone N.17 to Quaternary.

Genus **GLOBIGERINITA** Brönnimann, 1951**Globigerinita glutinata** (Egger)

Pl. 17, figs. 3-5

Globigerina glutinata Egger, 1893, Abh. K. Bayer. Akad. Wiss. München, CL II, vol. 18, p. 371, pl. 13, figs. 19-21.

Tinophodella ambitacrena Loeblich and Tappan, 1957, Washington Acad. Sci., Jour., vol. 47, No. 4, p. 114, pl., figs. 2, 3.

Globigerinoides parkerae Bermúdez, 1961, Bol. Geología, Pub. Esp. No. 3; Mem. Terc. Congr. Geol. Venezolano, tom. 3, p. 1232, pl. 10, figs. 10, 11.

Globigerinita glutinata (Egger), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 246, pl. 9, figs. 1-16.

This species is like the warm-water form figured by Parker (1962, pl. 9, figs. 1-9). It occurs throughout the core sections from Zone N.16—Quaternary, almost always in abundance.

Globigerinita iota Parker

Pl. 17, figs. 6, 7

Globigerinita iota Parker, 1962, Micropaleont., vol. 8, No. 2, p. 250, pl. 10, figs. 26-30.

Additional synonymy is given in the above reference. This species apparently developed high in Zone N.19, presumably from *G. glutinata*, although this evolution was not observed.

Globigerinita uvula (Ehrenberg)

Pl. 17, figs. 8, 9

Pylodexia uvula Ehrenberg, 1861, K. Preuss. Akad. Wiss. Berlin, Monatsber., pp. 276, 277, 308.

Pylodexia uvula Ehrenberg, 1873, K. Akad. Wiss. Berlin, Abh., Jahrg. 1872, pl. 2, figs. 24, 25.

Globigerina sp. Brady, 1884, Rept. Voy. *Challenger*, Zoology, vol. 9, p. 603, pl. 82, figs. 8 (lectotype of *Globigerina bradyi* Wiesner), 9.

Globigerina bradyi Wiesner, 1931, in Drygalski, Deutsche Südpolar Exped. 1901-1903, Bd. 20 (Zoology, Bd. 12), p. 133.

Globigerinoides minuta Natland, 1933, Univ. Calif., Scripps Inst. Oceanography, Tech. Ser., vol. 3, No. 10, line 34 of table (*nomen nudum*).

Globigerinoides minuta Natland, 1938, Univ. Calif., Scripps Inst. Oceanography, Tech. Ser., vol. 4, No. 5, p. 150, pl. 7, figs. 2, 3.

Globigerina bradyi Wiesner, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 5, pl. 3, figs. 1 (lectotype), 2.

Globigerinita uvula (Ehrenberg), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 252, pl. 8, figs. 14-26.

This species occurs throughout the core sections from Zone N.16—Quaternary. It was not found in all cores, however.

Genus **TURBOROTALITA** Blow and Banner, 1962**Turborotalita humilis** (Brady)

Pl. 17, figs. 10

Truncatulina humilis Brady, 1884, Rept. Voy. *Challenger*, Zoology, vol. 9, p. 665, pl. 94, fig. 7.

- Globigerina cristata* Heron-Allen and Earland, 1929, Jour. Roy. Micr. Soc., ser. 3, vol. 49, pt. 4, art. 27, p. 331, pl. 4, figs. 33-39.
- Globigerinita parkerae* Loeblich and Tappan, 1957, Washington Acad. Sci., Jour., vol. 47, No. 4, p. 113, pl., fig. 1.
- Globigerina cristata* Heron-Allen and Earland, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 10, pl. 7, fig. 5 (lectotype).
- Truncatulina humilis* Brady, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 36, pl. 8, fig. 1 (lectotype).
- Globigerinita humilis* (Brady), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 249, pl. 10, figs. 1-25.

This species apparently occurs throughout the core sections from Zone N.17-Quaternary. In the older sections, where solution effects are greatest, the specimens are not well preserved, and it is difficult to tell if they are identical to the stratigraphically younger forms. Solution is apt to dissolve away the wall at the sutures and around the lobe extending from the final chamber down over the umbilicus. In most of the Pliocene section the species seems less variable than in the Quaternary, and the more lobulate variants are not seen. Again, this lack of variation may be a function of the amount of solution, because the less lobulate forms are usually sturdier.

Family **HANTKENINIDAE** Cushman, 1927

Genus **GLOBANOMALINA** Haque, 1956

This genus was described by Haque as being trochoid, although sometimes almost bisymmetrical (at least in the type species, *G. ovalis* Haque). Loeblich and Tappan (1964) put *Pseudobastigerina* Banner and Blow, 1959, into the synonymy of Haque's genus, but at the present time I am not prepared to give an opinion on the validity of combining these two genera. *Globanomalina* is used here to provide a niche for two species, one of which (*G. (?) pumilio*) apparently evolved from the other (*G. praepumilio*), although this evolution has not been fully substantiated. A case might be made for referring *G. (?) pumilio* to *Globorotalia*, as was originally done, but *G. praepumilio* has a peripheral aperture which is sometimes slightly asymmetrical. This species appears to be nearly planispiral, but the small size and the involution make this difficult to determine with absolute assurance. The test walls of both species are smooth, not spinose (even secondarily), and finely perforate.

Globanomalina has not been reported from strata younger than Oligocene, but its small size or possible elimination by solution could account for its having been unobserved.

Globanomalina praepumilio, n. sp.

Pl. 18, figs. 1-4

Description.—Test small, planispiral or slightly asymmetrical, partially involute, with a rounded periphery; chambers increasing in size and inflation gradually as added, $5\frac{1}{2}$ to 8 in the final whorl, usually 6 or 7, about 15 in all; sutures slightly curving, somewhat depressed, especially the later ones, narrow; wall thin, smooth, often somewhat translucent, finely perforate; aperture a narrow, short, curved opening at the periphery, sometimes slightly asymmetrical in position, with a narrow lip. Specimens up to 0.12 mm in diameter.

Holotype.—DODO 117 P, 164-166 cm. Lat. $18^{\circ}21'S$, long $62^{\circ}04'E$, 3398 m; Indian Ocean. Upper Pliocene, Banner and Blow Zone N.21. USNM No. 642982.

Remarks.—This species was found in two cores; in DODO 117 P it occurs in the upper part of Zone N.20 and in N.21; in DODO 57 P it is found in one sample from Zone N.21. It appears to give way to *G. (?) pumilio*, but this evolution has not been definitely established. Many small forms have not yet been described, partly because they are not sufficiently striking to be easily identified. This species, however, is easily differentiated in well-preserved material. Unfortunately, in the Pacific and Indian Oceans well-preserved material of this age is comparatively rare. Eventually this species may be found to range lower in the section, and its ancestry may be discovered. It shows little variation, aside from the number of chambers in the final whorl and the width of the aperture. It differs from *G. ovalis* in being less trochoid, in its peripheral aperture which does not extend to the umbilicus, and in its smaller size.

Globanomalina (?) pumilio (Parker)

Pl. 18, fig. 5

Globorotalia pumilio Parker, 1962, Micropaleont., vol. 8, No. 2, p. 238, pl. 6, figs. 2, 3.

This species was found only in the Quaternary, presumably having evolved from *G. praepumilio* above Banner and Blow's Zone N.21. This evolution has not been verified but *G. (?) pumilio* only occurs in the cores above the extinction point of *G. praepumilio* which appears to be the only species from which it could have developed. The slight asymmetry of *G. praepumilio* shows that there may have been a tendency on the part of that species to become increasingly trochoid.

Family **GLOBIGERINIDAE** Carpenter, Parker and Jones, 1862

This family includes the forms which have long, thin spines when living. Most of them have small, sharp primary spines on the empty tests of adults or juveniles. The description of the family is the same as that given by Parker (1962), and the included genera are the same also except that *Pulleniatina* is excluded. *Globigerinoides* is considered to be polyphyletic and will be discussed under that genus.

Genus **GLOBIGERINA** d'Orbigny, 1826

Beella Banner and Blow, 1960, is considered to be a synonym of *Globigerina*.

Globigerina calida Parker

Pl. 18, figs. 6-12

Globigerina calida Parker, 1962, Micropaleont., vol. 8, No. 2, p. 221, pl. 1, figs. 9-13, 15.

Specimens of a primitive form (Pl. 18, figs. 6-8) of this species were seen throughout the core sequences from the upper part of Zone N.17 to Zone N.21, where the species became more nearly typical (Pl. 18, figs. 9, 10, 12) although even then no specimen was seen with the elongate chambers of some adult, modern specimens (Pl. 18, fig. 11). The modern form includes specimens like the primitive form within its range of variation. Pleistocene sequences will have to be studied to determine exactly what the history of the species is. Specimens are never numerous, and for this reason no attempt has been made to designate a new taxon for the primitive form.

Globigerina decoraperta Takayanagi and Saito

Pl. 19, figs. 1, 2

Globigerina druryi Akers *decoraperta* Takayanagi and Saito, 1962, Sci. Repts. Tohoku Univ., ser. 2 (Geology), Spec. vol. No. 5, p. 85, pl. 28, fig. 10.

This compact species has a spire which varies a good deal in height and an aperture which varies in size, although typically it is large. The specimens compare well with those sent by T. Saito. They occur in the lower part of most of the cores, ranging up into Zone N.20 where the species changed to the form known as *G. rubescens*. The change was a gradual one, and specimens can be found in assemblages of either species which are much alike. *G. decoraperta* is usually somewhat larger, has less inflated chambers, a somewhat smoother wall and typically a larger aperture, although specimens with small ones also occur. This species is

not ideal for stratigraphic interpretation because of its nondescript character. Young forms of other species often look like it. For this reason it did not seem worthwhile to illustrate the morphological variations to any great extent. T. Huang (1966) stated that *G. nepenthes* of Takayanagi and Saito (not Todd) is a synonym of this species; both forms were reported by those authors from the Nobori Formation of Japan.

Globigerina digitata Brady

Pl. 19, fig. 9

Globigerina digitata Brady, 1879, Quart. Jour. Micr. Sci., new ser., vol. 19, p. 286.
Globigerina digitata Brady, 1884 (part), Rept. Voy. Challenger, Zoology, vol. 9, p. 599, pl. 80, figs. 6-10 (not pl. 82, figs. 6, 7).

Globorotalia (*Hastigerinella*) *digitata* (Brady), Banner and Blow, 1959, Palaeontology, vol. 2, pt. 1, p. 16, text fig. 4e (lectotype).

Globorotalia (*Beella*) *digitata* (Brady), Banner and Blow, 1960, Micropaleont., vol. 6, No. 1, p. 26, text fig. 11 (lectotype).

Globigerina digitata Brady, Parker, 1962, Micropaleont., vol. 8, No. 2, p. 222, pl. 1, figs. 20-25.

This species developed from *G. praedigitata* near the top of Zone N.21, or possibly somewhat higher in the Pleistocene. The specimens at 408-410 cm in CAP 38 BP, the first Pleistocene sample in that core, include forms which might be considered transitional, but they are too few in number for one to be sure of the range of variation. In other cores the species either appeared above the base of the Pleistocene or in samples whose exact locations in the Pleistocene are unknown. Pre-Pleistocene reports of this species are referable to other forms, mostly to *Sphaeroidinella seminulina*. The specimen figured by Lipps (1964, pl. 2, fig. 2) as *G. cf. G. digitata* is probably an aberrant specimen of some other species, a view with which he concurs (personal communication).

Globigerina falconensis Blow

Pl. 19, fig. 11

Globigerina falconensis Blow, 1959, Bull. Amer. Paleont., vol. 39, No. 178, p. 177, pl. 9, figs. 40, 41.

Globigerina falconensis Blow, Parker, 1962, Micropaleont., vol. 8, No. 2, p. 224, pl. 1, figs. 14, 16-19.

Specimens are rare and small in the core sequences, probably because, according to present-day evidence, the species is more common in the temperate zones than in the tropics. It occurs in core samples from Zones N.20, N.21 and Quaternary, but has been reported from as far down as the lower Miocene.

Globigerina nepenthes Todd

Pl. 19, fig. 10

Globigerina nepenthes Todd, 1957, U. S. Geol. Sur., Prof. Paper 280-H, p. 301, pl. 78, fig. 7.

At the top of the range of this species, specimens sometimes occur which are nondescript and questionably referable to it, but in the present study only typical *G. nepenthes* has been recognized as such and reported in the range charts. It occurs in the cores from Zone N.16 (the lowest zone reported) up into the lower part of Zone N.19. This species has usually been reported as occurring only in the Miocene, but in the cores it overlaps *Sphaeroidinella debiscens*, the index fossil recognized here as indicating the Pliocene, for a considerable distance.

***Globigerina praedigitata*, n. sp.**

Pl. 19, figs. 5-8

Description.—Test medium in size with broadly rounded periphery, lobulate, chambers often irregularly placed; chambers rounded or club-shaped, inflated, up to 14 or 15 in number, 4 to 5 in the last-formed whorl; sutures depressed; wall thin, spinose or almost smooth with only the rounded spine bases protruding; aperture often irregularly shaped, narrow to semicircular, marginal or interiomarginal, with a lip of varying width. Largest diameter about 0.6 mm.

Holotype.—CAP 38 BP, 579-582 cm. Lat 14°16'S., long. 119°11'W., 3400 m; Pacific Ocean. Lower Pliocene, Banner and Blow Zone N.19. USNM No. 643000.

Remarks.—This species is close to *G. digitata*, only differing in not having the long, pointed digitate chambers. Many of the specimens seen in an assemblage of *G. digitata* are identical, especially juvenile forms. This new species is never common in any one sample. It occurs first in samples from Zone N.17 but, since little material from Zone N.16 was seen, the position of its first appearance is uncertain. It was replaced by *G. digitata* either at the base of the Pleistocene or somewhat higher.

***Globigerina* cf. *G. quinqueloba* Natland**

Pl. 18, figs. 13, 14

cf. *Globigerina quinqueloba* Natland, 1938, Univ. Calif., Scripps Inst. Oceanography, Bull. Tech. Ser., vol. 4, No. 5, p. 149, pl. 6, fig. 7.

cf. *Globigerina groenlandica* Stschedrina, 1946, Artich. Nauch. Issl. Inst. Dreif. Eksped. Glavs. Ledok. Parokh. "G. Sedov" 1937-1940, Trudy, vol. 3 (Biology), p. 145, pl. 4, fig. 23.

cf. *Globigerina quinqueloba* Natland, Parker, 1962, Micropaleont., vol. 8, No. 2, p. 225, pl. 2, figs. 7-16.

G. quinqueloba was reported (Parker, 1962) as occurring only as far north as lat. 19°S. in the South Pacific. This report was based on sieved material larger in diameter than 0.149 mm. Small specimens, however, which resemble *G. quinqueloba* closely, are common in the tropics and are also common in the fine material of the present cores, in samples where

there has not been a great deal of solution of calcium carbonate. In the cores the species occurs first in the upper part of Zone N.17, and somewhat atypical specimens occur in a sample from Zone N.17 in Fiji.

Globigerina rubescens Hofker

Pl. 19, figs. 3, 4

Globigerina rubescens Hofker, 1956, *Spolia Zoologica Musei Hauniensis*, vol. 15, p. 234, pl. 35, figs. 18-21.

Globigerina rubescens Hofker, Parker, 1962, *Micropaleont.*, vol. 8, No. 2, p. 226, pl. 2, figs. 17, 18.

This species apparently developed from *G. decoraperta* in Zone N.20. The process was gradual, and the demarcation between the species cannot be pinpointed. At first, *G. rubescens* is white in color, and it is not known when the color change came or whether, in fact, the color has been bleached from the fossil specimens. Faintly pink specimens occur in CAP 38 BP at 145-150 cm, so perhaps the red color developed in the Pleistocene or, if bleaching takes place, can persist from Pleistocene times. In the Recent Pacific sediments white specimens occur in the higher-latitude area of its distribution (Parker, 1962).

Genus **GLOBIGERINELLA** Cushman, 1927

This genus (type species *Globigerina aequilateralis* Brady=*G. siphonifera* d'Orbigny) is nonpolyphyletic if one includes in it only the type species and *Globigerinella adamsi*. It would be permissible to include also "*Globorotalia*" *obesa* Bolli which is the direct forerunner of *Globigerinella siphonifera*, but perhaps it would be better to consider that species the globigerine ancestor of the genus *Globigerinella*.

Globigerinella adamsi (Banner and Blow)

Globigerina digitata Brady, 1884 (part), Rept. Voy. *Challenger*, Zoology, vol. 9, pl. 82, figs. 6, 7 (not pl. 80, figs. 6-10).

Globigerinella sp., Bradshaw, 1959, *Contr. Cushman Found. Foram. Res.*, vol. 10, p. 38, pl. 7, figs. 3, 4.

Hastigerina (*Bolliella*) *adamsi* Banner and Blow, 1959, *Palaeontology*, vol. 2, pt. 1, p. 13, text fig. 4.

Globigerinella adamsi (Banner and Blow), Parker, 1962, *Micropaleont.*, vol. 8, p. 226, pl. 2, figs. 19-21.

This species occurs only in the top samples of two cores and is presumably Recent in age. It apparently developed from *G. siphonifera*.

Globigerinella siphonifera (d'Orbigny)

Pl. 22, fig. 5

Globigerina siphonifera d'Orbigny, 1839, *in* de la Sagra, *Hist. Phys. Pol. Nat. Cuba*, "Foraminifères", p. 83, pl. 4, figs. 15-18.

- Globigerina aequilateralis* Brady, 1879, Quart. Jour. Micr. Sci., new ser., vol. 19, p. 285.
- Globigerina aequilateralis* Brady, 1884, Rept. Voy. *Challenger*, Zoology, vol. 9, p. 605, pl. 80, figs. 18-21.
- Globigerina aequilateralis* Brady var. *involuta* Cushman, 1917, U. S. Nat. Mus., Proc., vol. 51, No. 2172, p. 662.
- Globigerina aequilateralis* Brady var. *involuta* Cushman, Cushman, 1921, U. S. Nat. Mus., Bull. 100, vol. 4, p. 293, text fig. 11.
- Hastigerina* (*Hastigerina*) *siphonifera* (d'Orbigny), Banner and Blow, 1960, Micropaleont., vol. 6, No. 1, p. 22, text figs. 2 (lectotype), 3.
- Globigerinella siphonifera* (d'Orbigny), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 228, pl. 2, figs. 22-28.

This species ranges through the whole section studied in the cores. The specimens are of the "group 1" type mentioned earlier (Parker, 1962); they are initially trochoid, becoming planispiral and involute.

Genus **GLOBIGERINOIDES** Cushman, 1927

This genus, as presently interpreted, is undoubtedly polyphyletic. It is used here, however, because the lineages of the included species are not sufficiently understood to make certain to what genera the forms should be referred. It is probable that most of them could be included in *Globigerina*. Exceptions may be forms referred by workers to *Globigerinoides trilobus* (Reuss), *G. quadrilobatus* (d'Orbigny), and *G. sacculifer* (Brady), together with various combinations of these names and so-called subspecies thereof. The most logical genus for this group appears to be *Sphaeroidinella*, to which *Globigerinoides sacculifer* has been shown to be related by Bé (1965). Bé maintained that *G. sacculifer* and *Sphaeroidinella debiscens* are forms of the same species, but this seems doubtful. The logical conclusion to draw from such a premise would be that similar affiliations should be found between fossil species of *Sphaeroidinella* (including species referred by some to *Sphaeroidinellopsis*) and contemporary species of *Globigerinoides*, and this appears to be impossible. For example, one cannot find in the *G. sacculifer* group any reflection of the development of *Sphaeroidinella debiscens* from *S. subdebiscens*. This group of *Globigerinoides* species is not transferred to *Sphaeroidinella* here because the earlier members have not been studied. The lineages described by authors must be carefully examined so that the limits of the genus can be defined and its point of origin decided.

Globigerinoides bollii Blow

Pl. 20, figs. 1, 2

Globigerinoides bollii Blow, 1959, Bull. Amer. Paleont., vol. 39, No. 178, p. 189, pl. 10, fig. 65.

Specimens were compared with the holotype, and they have slightly more flattened final chambers but not to the extent seen in *G. obliquus*. The specimens from the highest Miocene and Pliocene usually have a somewhat larger single dorsal aperture (Pl. 20, fig. 2) instead of the two seen in earlier forms (Pl. 20, fig. 1), but specimens with the two small dorsal apertures occur also. The species ranges up into the lower part of Zone N.21.

Globigerinoides conglobatus (Brady)

Pl. 20, figs. 3, 4

Globigerina conglobata Brady, 1879, Quart. Jour. Micr. Sci., new ser., vol. 19, p. 286.

Globigerina conglobata Brady, 1884, Rept. Voy. *Challenger*, Zoology, vol. 9, p. 603, pl. 80, figs. 1-5; pl. 82, fig. 5.

Globigerina conglobata Brady, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 6, pl. 4, fig. 4 (lectotype).

Globigerinoides conglobatus (Brady), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 229, pl. 3, figs. 1-5.

The range of variation in the Pliocene is similar to that in the Recent, although specimens with large, open apertures are less common. The present material is limited, but apparently the Miocene specimens are narrow-apertured. Bullae covering the apertures are common. The species occurs throughout the section studied.

Globigerinoides fistulosus (Schubert)

Pl. 21, figs. 3, 5, 6; Text-fig. 4

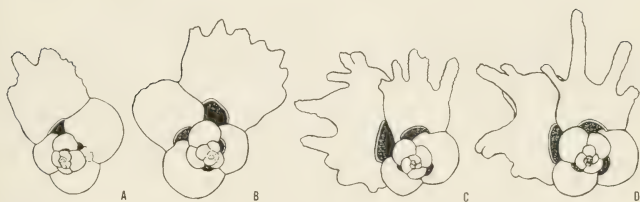
Globigerina fistulosa Schubert, 1910, Verh. k. k. geol. Reichsanst., p. 323, text fig. 2.

Globigerina fistulosa Schubert, 1911, Abh. k. k. geol. Reichsanst., Band 20, Heft. 4, p. 100, text fig. 13.

Globigerinoides quadrilobatus (d'Orbigny) *hystricosus* Belford, 1962, Bur. Mineralog. Res., Geology, Geophysics, Bull. No. 62-1, p. 17, pl. 4, figs. 11-14.

This species is believed to have evolved from the typical form of *G. sacculifer* (*q.v.*), and many specimens retain the elongate flattened final chamber of that form, embellished with heavy spines. The nonspinose juveniles cannot be separated from those of *G. sacculifer*.

The type specimen, as well as specimens figured by Belford both as *G. quadrilobatus hystricosus* (see synonymy) and *G. quadrilobatus fistulosus* (Belford, 1962, pl. 4, figs. 7-10), LeRoy (1964, pl. 14, fig. 17), and McTavish (1966, pl. 7, figs. 14, 17, 18), all appear to be phylogenetically primitive. Such specimens occur in the upper part of Zone N.19 and the lower part of N.20 in DODO 117 P, which contains a good development sequence of this species (Text-fig. 4). The species is well developed in the upper part of Zone N.20, and the specimens figured by Schubert (1911), Cushman, Todd, and Post (1954, pl. 91, fig. 13), Hamilton and Rex (1959, pl. 254, fig. 14), and Todd (1964, pl. 290, fig. 6) all appear



Text-figure 4. Evolutionary series of *Globigerinoides fistulosus* (Schubert).

DODO 117P; A, 451-453 cm; B, 230-232 cm; C, 108-110 cm; D, 68-70 cm. X24. USNM No. 643109.

to be such specimens. The faunas accompanying these figured specimens seem to bear out the occurrences in DODO 117 P, except for the specimen figured by Hamilton and Rex, which is accompanied by a group of species which can be referred either to late Miocene or the Pliocene Zone N.19. However, since these authors state that Recent planktonic species are present and the sample is a dredge haul, it is possible that specimens of various ages are present.

Assemblages from Zone N.21 contain specimens of a primitive type, as well as advanced ones, but the supposition is that the figured specimens listed above represent the most advanced forms encountered. The species apparently ranges from the lower part of Zone N.19 to near the top of N.21 or slightly higher.

***Globigerinoides obliquus* Bolli**

Pl. 20, figs. 5, 6

Globigerinoides obliquus Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 113, pl. 25, figs. 9, 10; text fig. 21, No. 5.

Globigerinoides obliquus extremus Bolli and Bermúdez, 1965, Bol. Inform. Asoc. Venezolana, Geología, Minería y Petróleo, vol. 8, No. 5, p. 139, pl. 1, figs. 10-12.

Most specimens are like those figured by Bolli and Bermúdez as their subspecies (I have specimens sent to me by H. M. Bolli and P. J. Bermúdez), but towards the top of the species range, the specimens appear to be more like the typical form. The species ranges up into the lower part of Zone N.21. This range is similar to that given by Bolli (1966b, p. 462) for *G. obliquus extremus* in well Bodjonegoro-1 in Java. He said that this subspecies became extinct a few meters above the extinction of *Globoquadrina altispira*, which in the cores seemingly disappeared in basal N.21. If Zone N.20 is a reality and is not well represented in the cores because of its brevity, *G. altispira* theoretically became extinct at the base of Zone N.20 (according to Banner and Blow, 1965b).

Globigerinoides ruber (d'Orbigny)

Pl. 22, figs. 1-4

Globigerina rubra d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminifères," p. 82, pl. 4, figs. 12-14.

Globigerina rubra d'Orbigny, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 19, pl. 3, fig. 8 (lectotype).

Globigerinoides ruber (d'Orbigny), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 230, pl. 3, figs. 11-14; pl. 4, figs. 1-10.

Typical *G. ruber* (Pl. 22, fig. 3) (Parker, 1962, pl. 3, figs. 11-13) does not occur in the core sequences until Zone N.21. Earlier specimens (Pl. 22, fig. 1) are like present-day high-latitude forms (Parker, 1962, pl. 4, figs. 6-9) which are referred by some workers to *G. elongatus* (d'Orbigny). Whether or not typical *G. ruber* occurs lower in other areas is somewhat problematical, although specimens figured by some workers from the "Miocene" certainly appear to be of this type.

A form referred here to *G. ruber* variant (Pl. 22, fig. 4) first occurs in Zone N.20. This form has flattened chambers, and there is a possibility that it may have developed from *G. obliquus*, although no evidence for this evolution was seen in these cores. Recent forms referred to "group 2" of Parker (1962, pl. 3, fig. 14; pl. 4, figs. 1-5) include specimens like this variant. They also include specimens like that figured here (Pl. 22, fig. 2) which were not especially noted in the cores below the appearance of the typical form.

The *G. ruber* group is not well represented in cores where much solution has occurred, and for this reason no intensive work was done on this group.

Globigerinoides sacculifer (Brady)

Pl. 21, figs. 1, 2, 4; Text-fig. 5

Globigerina sacculifera Brady, 1877, Geol. Mag., new ser., decade 2, vol. 4, No. 12, p. 535.

Globigerina sacculifera Brady, Brady, 1879, Quart. Jour. Micr. Sci., new ser., vol. 19, p. 287.

Globigerina sacculifera Brady, Brady, 1884, Rept. Voy. *Challenger*, Zoology, vol. 9, p. 604, pl. 80, figs. 11-17; pl. 82, fig. 4 (these figured specimens are from oceanic surface sediments and plankton).

Globigerina sacculifera Brady, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 21, pl. 4, figs. 1 (lectotype), 2.

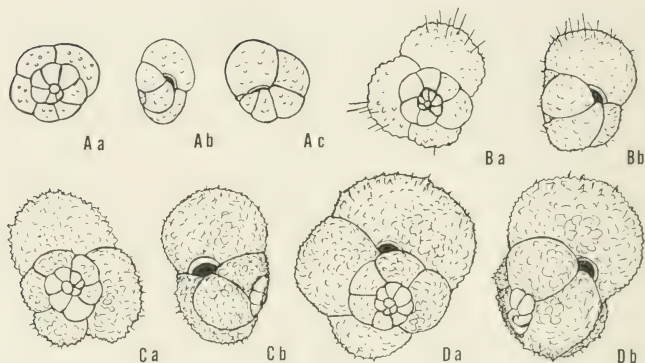
Globigerinoides quadrilobatus sacculifer (Brady), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 229, pl. 3, figs. 6-10.

The earlier decision to make *G. sacculifer* a subspecies of *G. quadrilobatus* (d'Orbigny) has been rescinded in order to confine the subspecific category to geographical subspecies. The two forms are undoubtedly related if one accepts the lectotype chosen by Banner and Blow. In the case of Brady's (1964a) lectotype, the I. C. Z. N. (Art. 746) states that

"designation of a figure as lectotype is to be treated as designation of the specimen represented by the figure . . .". Apparently such a designation is legal but seems unfortunate when it is known that the specimen does not exist. The specimens from Zone N.17 in the cores may be referable to the species represented by the Banner and Blow lectotype of "*Globigerina quadrilobatus*" but in view of the existing confusion regarding the whole "*Globigerina quadrilobatus*" question, they are referred here to phylogenetically primitive *Globigerinoides sacculifer*.

Dr. C. G. Adams of the British Museum (Natural History) kindly provided a sample from the "type locality" of *G. sacculifer*. The type sample is described by Liversidge (1877) as a fragment from a carved figure composed of foraminiferal "chalk" picked up on the beach on the east side of New Ireland (Bismarck Archipelago) by a Wesleyan missionary, Dr. G. Brown. A number of carved idols of men and animals were picked up, and when Dr. Brown was asked for information concerning the locality and mode of occurrence of the material used for the carvings, he replied (Liversidge, 1877, p. 86): "The chalk of which the figures are formed is, I am informed, only found on the beach after an earthquake, being cast up there in large pieces by the tidal wave; it is only found, as far as we know at present, in one district on the east side of New Ireland." Thus, the origin of this chunk of carving is unknown. The sample contains an excellent planktonic fauna including: *Globigerina nepenthes*, *Globigerinoides obliquus*, *Globoquadrina altispira*, *G. debiscens*, *G. humerosa*, *G. venezuelana*, *Globorotalia tumida* (this is the type locality of this species, also; flexuose specimens are included in the assemblage), *Pulleniatina primalis*, *Sphaeroidinella seminulina*, *S. subdebiscens*. The sample fits well into Banner and Blow's Zone N.18 and is considered to be late Miocene in age. It may well be close to the Miocene-Pliocene boundary, judging from the large size of some specimens of *S. subdebiscens*.

The specimens of *Globigerinoides sacculifer* in the type sample are mostly of the "*trilobus*" type, but good specimens with a sac-chamber also occur. Specimens of analogous age in the cores have a characteristic compressed, elongate sac-chamber, and a few such specimens were observed in the type sample as well (for a core specimen see Pl. 21, fig. 1). An assemblage of typical specimens can be differentiated from a modern one by the presence of this more compressed paddle-shaped sac-chamber, but the difference is so slight and difficult to convey either by description or figures that no nomenclatural discrimination has been made between the



Text-figure 5. Early growth stages of *Globigerinoides sacculifer* (Brady).

Stages are progressively older from A to D. VS 45, Gulf of California, 17 cm net tow, 0-50 m. X ca. 160. USNM No. 643110.

two types. Such minor differences are familiar to workers concentrating on a short stratigraphic sequence in a particular area, and while useful are of value only to that specific worker. It seems senseless to clutter up the classification with such, because so much confusion can be caused by misinterpretation. The lectotype chosen by Banner and Blow does not show this type of sac-chamber.

G. sacculifer is an interesting species because of the unusual characteristics of the early chambers, which are different from those of such species as *G. ruber* or *G. conglobatus*. Text-fig. 5 shows a sequence of young specimens at various stages of growth. The early chambers can be seen so much more easily in plankton specimens than in fossil ones that these figured specimens were taken from a Gulf of California plankton sample. The first two whorls form a test that is flat on the coiled side, has six-seven chambers in the first whorl, and a finely perforate glassy wall. Later, the chambers begin to increase much more rapidly in size and the characteristic coarse pores and long spines begin to appear. The early flattened part can be seen even in adult specimens, although often considerable wall thickening has taken place. This early stage differs greatly from those of *G. ruber* and *G. conglobatus*, which have an initial whorl of five rounded, globigerine chambers.

The suggested synonymy of this species with *Sphaeroidinella debiscens* by Bé (1965), as well as the reasons for believing the two forms to be distinct species, were discussed under the genus *Globigerinoides*. Poor specimens which appear to be primitive *G. sacculifer* occur in Zone N.16 samples from PROA 88 P and in Zone N.17; typical specimens occur in Zones N.18-N.20. At the base of Zone N.21 there is a transition to assemblages of specimens of the modern type.

Globigerinoides tenellus Parker

Globigerinoides tenella Parker, 1958, Repts. Swedish Deep-Sea Exped. 1947-48, vol. 8, No. 4, p. 280, pl. 6, figs. 7-11.

Globigerinoides tenellus Parker, 1962, Micropaleont., vol. 8, No. 2, p. 232, pl. 4, figs. 11, 12.

This species does not appear in the cores until the Quaternary. It has not been refigured here because it is adequately illustrated in the above references.

Genus **HASTIGERINA** Thomson, 1876

Hastigerina pelagica (d'Orbigny)

Pl. 22, fig. 6

Nonionina pelagica d'Orbigny, 1839, Voy. Amér. Merid., "Foraminifères", vol. 5, pt. 5, p. 27, pl. 3, figs. 13, 14.

Hastigerina murrayi Thomson, 1876, Roy. Soc. London, Proc., vol. 24, No. 534, pls. 22, 23 (lectotype is the lower specimen on pl. 22).

Hastigerina pelagica (d'Orbigny), Brady, 1884, Rept. Voy. Challenger, Zoology, vol. 9, p. 613, pl. 83, figs. 1-8 (neotype is pl. 83, fig. 4).

Hastigerina (Hastigerina) pelagica (d'Orbigny), Banner and Blow, 1960, Micropaleont., vol. 6, No. 1, p. 20, text fig. 1.

Hastigerina pelagica (d'Orbigny), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 228.

This species occurs rarely in the cores in samples from Zone N.17 to Recent. The fragility of the test is probably responsible for its rarity.

"Genus **ORBULINA** d'Orbigny 1839"

Orbulina spp.

Pl. 22, figs. 7, 8

So-called *Orbulina universa* d'Orbigny is present throughout the core sequences. As pointed out by various workers (Rhumbler, 1911; Parker, 1962; Bandy *et al.*, 1965) this form may embrace a variety of species or even genera, all of which probably are of globigerine origin. A characteristic bilobate form of *Orbulina* (Pl. 22, fig. 7) is present in the core

sequences from Zones N.16 to N.18. One exception is the occurrence of specimens at MSN 56 P, 161-163 cm (Zone N.19 or N. 20), but because no specimens were seen lower in the core, these may be contaminants. This form differs from modern bilobate specimens (Pl. 22, fig. 8) in being much more pinched in at the central portion. Whether or not it is the same as "*Globigerina bilobata*" d'Orbigny is not certain.

Genus **SPHAEROIDINELLA** Cushman, 1927

The genus *Sphaeroidinellopsis* is considered to be synonymous with *Sphaeroidinella*. A plea for keeping that genus would be stronger if its type species were *S. seminulina* rather than *S. subdehiscens*, but *S. subdehiscens* is so closely allied to its descendant *S. dehiscens* that it seems unrealistic to separate them generically. *S. seminulina* differs from *S. dehiscens* not only in apertural characteristics but in wall character as well, having a much thinner cortex. The possibility of eliminating the polyphyletic genus *Globigerinoides* was discussed in the introduction to this section together with the suggestion that in that event *G. saeculifer* and its relatives might be included in *Sphaeroidinella*.

Aside from putting the original references of the various taxa in the appropriate synonymies, no attempt has been made here to evaluate the subsequent citations. Many figured specimens have been put in the synonymy of various species and the necessity of using specimens rather than figures to evaluate species is well illustrated here. Part of the apparent complication arises from the fact that most of the named species of *Sphaeroidinella* are, in fact, referable to *S. seminulina*.

Sphaeroidinella dehiscens (Parker and Jones)

Pl. 23, figs. 8, 9

Sphaeroidina bulloides d'Orbigny var. *dehiscens* Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., vol. 155, p. 369, pl. 19, fig. 5.

Sphaeroidina dehiscens Parker and Jones var. *immatura* Cushman, 1919, Carnegie Inst. Washington, Pub. No. 291, p. 40, pl. 14, fig. 2.

Sphaeroidina bulloides d'Orbigny var. *dehiscens* Parker and Jones, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 35, pl. 7, fig. 3 (lectotype).

Sphaeroidinella dehiscens (Parker and Jones), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 234, pl. 3, figs. 1, 2.

The appearance of this species in the section is the datum used here for the boundary between the Miocene and Pliocene, although this boundary rightfully should be placed slightly lower, as explained earlier. It marks also the boundary between Banner and Blow's Zones N.18 and N.19,

by definition. The species, as it first developed from *S. subdebiscens*, has a small opening on the side opposite the main aperture (Pl. 23, fig. 8); later the small aperture became larger and a more typical form of the species evolved (Pl. 23, fig. 9). Still later, apparently in Zone N.20, the form with the more complicated apertural characteristics seen in modern specimens appeared (Parker, 1962, pl. 3, fig. 1).

The form described as variety "*immatura*" by Cushman is phylogenetically primitive like the specimens found in the lower part of Zone N.19. It has a small supplementary aperture.

Sphaeroidinella seminulina (Schwager)

Pl. 23, figs. 1-5

Globigerina seminulina Schwager, 1866, *Norara* Exped. 1857-1859, Geol. Theil., Band 2, Abth. 2, p. 256, pl. 7, fig. 112.

Globigerina spec. Koch, 1923, *Eclogae Geol. Helvetiae*, vol. 18, No. 2, p. 355, text fig. 8.

Globigerina kochi Caudri, 1934, *Tertiary Deposits of Soemba*, Amsterdam, p. 144.

Sphaeroidinella disjuncta Finlay, 1940, Roy. Soc. New Zealand, Trans. Proc., vol. 69, pt. 1, p. 469, pl. 67, figs. 224-228.

Sphaeroidinella rutschi Cushman and Renz, 1941 (part), Contr. Cushman Lab. Foram. Res., vol. 17, p. 25, pl. 4, figs. 5a, b (holotype) (not fig. 5c, paratype).

Sphaeroidinella multiloba Le Roy, 1944, Quart. Colorado School Mines, vol. 39, No. 3, p. 91, pl. 4, figs. 7-9.

Globigerina grimsdalei Keijzer, 1945, Geog. Geol. Meded. Physiog.-Geol. Reeks., Utrecht, ser. 2, No. 6, p. 205, text fig. 33.

Globigerina seminulina Schwager, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 24, pl. 7, fig. 2 (neotype).

The variability of this species is probably the cause of the many species erected for it. In addition to the great diversity of shape and number of chambers in the final whorl ($3\frac{1}{2}$ to 6), the wall is variably reticulate and rugose. The cortex is more easily dissolved than is that of *S. debiscens* or *S. subdebiscens*. As a result a varying degree of reticulation and rugosity occurs, depending upon the amount of solution, sometimes perhaps with redeposition of calcium carbonate at a later time. The figured specimens show some of the variations seen, (Pl. 23, fig. 5) showing a specimen with a high degree of rugose reticulation and (Pl. 23, fig. 1) a specimen with a normal cortex. Other figures show intermediate stages between. Within the range of variation of the species are forms which are identical to specimens of *S. seminulina* obtained by J. A. Cushman from Schwager's original sample and sent to me by R. Todd. Specimens of *S. disjuncta* from the Altonian of New Zealand, sent to me by D. G. Jenkins, appear to be within the range of this species also.

S. seminulina ranges in the cores from Zone N.16 to the lower part of Zone N.21. Multichambered forms are not found in the N.16 material of PROA 88 P but are common in the N.17 material of CAP 38 BP and continue throughout most of the range of the species in the core.

Sphaeroidinella subdehiscens Blow

Pl. 23, figs. 6, 7

Sphaeroidinella rutschi Cushman and Renz, 1941 (part), Contr. Cushman Lab. Foram. Res., vol. 17, p. 25, pl. 4, fig. 5c (not holotype, figs. 5a, b) (in his original synonymy, when describing this species, Blow placed in synonymy Renz' (1948) copied figure of this paratype instead of the original figure of Cushman and Renz).

Sphaeroidinella dehiscens Stainforth (not Parker and Jones, 1865), 1948, Jour. Paleont., vol. 22, No. 2, p. 124, pl. 26, fig. 20.

Sphaeroidinella dehiscens Weiss (not Parker and Jones, 1865), 1955, Micro-paleont., vol. 1, p. 313, pl. 3, figs. 28, 29.

Sphaeroidinella rutschi Bolli (not Cushman and Renz, 1941), 1957, U. S. Nat. Mus., Bull. 215, pl. 26, figs. 6, 7.

Sphaeroidinella dehiscens subdehiscens Blow, 1959, Bull. Amer. Paleont., vol. 39, No. 178, p. 195, pl. 12, figs. 71, 72.

The above synonymy was given by Blow in his original description of this species. Other citations could probably be added, such as *S. seminulina* of Hamilton and Rex (1959, pl. 254, figs. 4, 5) from Sylvania Guyot. This specimen has not been seen.

It is probable that *S. spinulosa* Subbotina (in Bykova, *et al.* 1958, p. 61, pl. 11, figs. 6, 7) is synonymous with Blow's species, in which case her name would have priority, but again, no type material has been seen.

The holotype of *S. subdehiscens* was studied. Both typical specimens (Pl. 23, fig. 6) and large, rounded specimens (Pl. 23, fig. 7) occur in the cores. The latter are particularly characteristic of the species just before the development of *S. dehiscens*. The species ranges into the lower part of Zone N.19, being rapidly replaced by *S. dehiscens*.

Family **CATAPSYDRACIDAE** Bolli, Loeblich and Tappan, 1957

The type genus of this family is *Catapsydrax* Bolli, Loeblich, and Tappan, 1957. This genus is considered here to be restricted to species with walls pitted like those of the type species, *Globigerina dissimilis* Cushman and Bermúdez. Lipps (1966) came to the same conclusion on the basis of his test wall studies. Included also in this family are *Subbotina* and *Globoquadrina*. *Globorotaloides* s.s. is placed in the synonymy of *Globoquadrina*. The ancestral genus of this family appears to be *Subbotina*, from which probably developed the various lineages of *Globoquadrina*. These lineages can be subdivided into genera or subgenera when they have been

worked out, but in the meantime one can visualize *Globoquadrina* as a supergenus like *Globorotalia*, as that genus is here interpreted. *Catapsydrax*, apparently a small offshoot from the parent stock, comprises only a few species.

This view of the family differs from that of Lipps (1966) who considered that *Globorotaloides* is the parent genus. He referred "*Globigerina*" *pseudobulloides* Plummer to that genus, but Berggren (1962) believed that this species gave rise to *Subbotina triloculinoides* (Plummer), which may in turn be the parent genus of *Globoquadrina*, as well as of later species referred to *Globorotaloides* (including the type species *G. variabilis* Bolli).

Pulleniatina is included here, with some doubt. Banner and Blow (1967) said that *P. primalis* "appears to have evolved directly from *Globorotalia* (*Turborotalia*) *acostaensis*" and that these two forms "appear to be linked, in this Zone [N.17] by morphologically intermediate forms . . .". The use of the word "appear" implies some doubt on this point. No evidence for this evolution was observed in the Indo-Pacific cores, but sequences of the age reported for its occurrence are not well represented either.

Genus **GLOBOQUADRINA** Finlay, 1947, emended

Included with this genus are *Globorotaloides* s.s. (type species *G. variabilis* Bolli) and some species which have been referred to *Globorotalia*, *Turborotalia* and/or *Globigerina* by some authors. The reasons for this inclusion were given in the introduction to this section and in an earlier paper (Parker, 1962). Species having a pitted, nonspinose (when living) wall structure are considered to be referable to the Catapsydracidae, and therefore such species which have been referred to other families are reclassified. The genus *Globoquadrina* is characterized by a pitted wall structure. The test is trochoid. The aperture is interiomarginal, umbilical or umbilical-extraumbilical and is characterized by some form of tooth (or apertural flap). In *Globoquadrina* s.s. (type species, *G. debiscens*) these teeth extend into the umbilicus and the aperture is umbilical, but in some species where the aperture is umbilical-extraumbilical, the teeth may extend along the aperture and out over the umbilical area (as in *G. acostaensis*, for example). *G. continuosa* is also included here in *Globoquadrina*; it has a more reduced tooth than *G. acostaensis* and appeared in the stratigraphic section much earlier.

Sometimes the teeth are lacking in many specimens of a species assemblage, or even in all specimens. This absence may be partly owing to the ease with which the teeth are broken, as was shown when cleaning specimens for illustration. In addition, the teeth are thin and may be easily dissolved. Umbilical teeth are lacking in *G. dutertrrei* in the Gulf of Alaska, both in sediments and plankton (personal communication, B. J. Enbysk); otherwise these specimens have a range of variation similar to that of specimens found elsewhere having the teeth.

This genus is emended here to include related, pitted-wall species having umbilical-extraumbilical apertures and apertural teeth.

***Globoquadrina acostaensis* (Blow)**

Pl. 24, figs. 3-9

Globorotalia acostaensis Blow, 1959, Bull. Amer. Paleont., vol. 39, No. 178, p. 208, pl. 17, fig. 106.

This species has been referred to the genus *Globoquadrina* because it has a pitted-wall structure, a trochoid test, and long apertural teeth which in many cases project over the umbilical area, often forming what superficially appear to be bulla-like structures. These teeth, however, seldom become attached to the test wall except along the apertural margin of the final chamber and do not have the regular shape, thick wall, or manner of attachment of the bullae seen in *Catapsydrax*. They are easily broken and many specimens, especially from land sections, do not show them at all. The holotype (which has been studied) is such a specimen. Others sent to me by W. H. Blow show them well.

The aperture is umbilical-extraumbilical and is concealed when the apertural tooth of the final chamber is well developed. If this tooth is broken away the earlier teeth, very like those of *Globoquadrina* s.s., can be seen (Pl. 24, figs. 4, 9). Such triangular teeth are not characteristic of *Globorotalia*.

With time, *G. acostaensis* became progressively more umbilicate and the point at which a worker recognizes the development of *G. humerosa* is bound to be somewhat subjective. Banner and Blow (1967) reported that this development occurred near the top of Zone N.16. A Zone N.17 specimen, sent to me by W. H. Blow and identified by him as *G. humerosa*, is a borderline specimen which in my opinion is referable to *G. acostaensis*. However, the accompanying assemblage has not been studied. In the cores *G. humerosa* first occurs in Zone N.18. Specimens similar to *G. acostaensis* appear in the *G. humerosa* assemblage, but none is seen with the complicated tooth structure of the typical specimens. Workers who prefer to split

assemblages according to morphological variations might consider that *G. acostaensis* occurs higher than the range given here (for example, Banner and Blow, 1967, reported the range up into Zone N.22), but, as mentioned above, it does not seem to me that these variants are typical of *G. acostaensis*. A specimen of *G. humerosa* with a long, narrow tooth is figured (Pl. 24, fig. 10), but it is more umbilicate and the tooth is more depressed into the apertural and umbilical area than in typical *G. acostaensis*.

G. acostaensis occurs in Zones N.16-N.18 in the cores and developed into *G. humerosa* in Zone N.18, according to the assemblages seen in CAP 38 BP.

Globoquadrina altispira (Cushman and Jarvis)

Pl. 25, fig. 8

Globigerina altispira Cushman and Jarvis, 1936, Contr. Cushman Lab. Foram. Res., vol. 12, p. 5, pl. 1, figs. 13, 14.

Globoquadrina altispira globosa Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 111, pl. 24, figs. 9, 10.

The named subspecies is combined with *G. altispira* s.s. because it seems to have no special stratigraphic significance; in fact the assemblages sometimes appear to show a complete range of variation from one to another. No detailed study of this range was made, however, and there is no intention here of expressing a firm opinion about the positive identity of these taxa. A somewhat superficial examination leads to this supposition. No attempt has been made to illustrate the range of variation of this species, because it has already been adequately illustrated in many publications.

G. altispira ranges in the cores from Zones N.16 to basal N.21, except in DODO 117 P where a possible Zone N.20 is found. Its extinction presumably occurred at the base of Zone N.20, according to Banner and Blow's (1965b) definition of this zone (see also earlier discussion of Zone N.20).

Globoquadrina conglomerata (Schwager)

Pl. 27, fig. 4

Globigerina conglomerata Schwager, 1866, Novara Exped. 1857-1859, Geol. Theil. Band 2, Abth. 2, p. 255, pl. 7, fig. 113.

Globigerina conglomerata Schwager, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 7, pl. 2, fig. 3 (neotype).

Globoquadrina conglomerata (Schwager), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 240, pl. 6, figs. 11-18.

There are several species which resemble each other closely and which have similar juvenile stages. They include this species, *G. venezuelana*

from which *G. conglomerata* developed, and *G. pseudofoliata*, n. sp., which apparently branched off from *G. venezuelana* at the base of Zone N.19 (see Pls. 26, 27). It is almost impossible to pinpoint the transition from *G. venezuelana* to *G. conglomerata*, which apparently took place in the upper part of Zone N.21 and the basal Quaternary. Typical *G. conglomerata* has a much more open umbilicus and more inflated chambers than *G. venezuelana*. That the adult specimen figured as *G. venezuelana* trans *G. conglomerata* (Pl. 26, fig. 10) is still transitional can be seen by comparing it with the Recent specimens figured earlier (Parker, 1962).

Globoquadrina continuosa (Blow)

Pl. 24, figs. 1, 2

Globorotalia opima continuosa Blow, 1959, Bull. Amer. Paleont., vol. 39, No. 178, p. 218, pl. 19, fig. 125.

This species is referred to *Globoquadrina* for the same reasons given for so referring *G. acostaensis* (q.v.). In *G. continuosa* the apertural teeth are more rudimentary. According to Blow this species is ancestral to *G. acostaensis*, with transitional specimens between the two occurring in the *Globorotalia "menardii menardii" / Globigerina nepenthes* Zone (boundary between Zones N.15/N.16). Specimens comparable to *G. continuosa* specimens given me by W. H. Blow occur in PROA 88 P near the bottom of the core at 449-451 cm (Zone N.16). Higher in the core at 200-202 cm (also in Zone N.16), *G. acostaensis* occurs. A sample between contains neither species.

Globoquadrina dehiscens (Chapman, Parr, and Collins)

Pl. 26, figs. 1-3

Globorotalia dehiscens Chapman, Parr, and Collins, 1934, Linn. Soc. London, (Zoology), Jour., vol. 38, No. 262, p. 569, pl. 11, fig. 36.

Globorotalia quadraria Cushman and Ellisor, 1939, Contr. Cushman Lab. Foram. Res., vol. 15, p. 11, pl. 2, fig. 5.

Globorotalia dehiscens Chapman, Parr, and Collins, Finlay and Marwick, 1940, Roy. Soc. New Zealand, Trans., vol. 70, pp. 114, 123, subsequent lists.

Globoquadrina subdehiscens Finlay, 1947, New Zealand Jour. Sci. Technology, vol. 28, No. 5 (Sec. B), p. 291.

Globoquadrina quadraria (Cushman and Ellisor) var. *advena* Bermúdez, 1949, Cushman Lab. Foram. Res., Spec. Pub. 25, p. 287, pl. 22, figs. 36-38.

Globoquadrina larmeri Akers, 1955, Jour. Paleont., vol. 29, p. 661, pl. 65, fig. 4.

?*Globoquadrina obesa* Akers, 1955, Jour. Paleont., vol. 29, p. 661, pl. 65, fig. 5.

Globoquadrina dehiscens Chapman, Parr, and Collins, Hornibrook, 1961, New Zealand Geol. Sur., Paleont., Bull. 34 (1), p. 153, pl. 22, figs. 446, 447, 449 (holotype of *G. subdehiscens* Finlay).

The present specimens are similar to ones from the Gellibrand Clay (or Marl Bairnsdalian), Port Campbell District, Victoria, Australia, sent to me by N. H. Ludbrook.

This species is variable in the character of the final whorl—some specimens showing consecutive chambers that increase so rapidly in size that the flattened apertural face of the final chamber is entirely exposed. In others the three or four chambers of the final whorl increase in size more gradually, as added, so that from the umbilical side the apertural face is not visible, being almost entirely within the umbilicus, the umbilical ends of the chambers of the final whorl being almost the same height. The specimen figured by Bolli (1957, pl. 24, fig. 4) illustrates a specimen of this type excellently. The more common form is the adult figured here (Pl. 26, fig. 1) and the figured young stages (Pl. 26, figs. 2, 3), which closely resemble the adults except that their chambers increase even more rapidly in size as added. The flat evolute side is a characteristic feature of all variations, but the periphery varies from rounded to angled, and the umbilicus is more open in some specimens than others. Some variants of *G. venezuelana* (Pl. 26, figs. 6, 7), usually early stages, rarely adults, also may have flattened evolute sides, but the tests are much less high and, as mentioned under that species, do not have the downward curving sides of the apertural face so commonly seen in early stages of *G. debiscens*.

The types of *G. quadraria* and *G. quadraria advena* have not been seen, but for some time the consensus has been that the former is synonymous to *G. debiscens*. R. Cifelli kindly examined the types of Bermúdez' variety and believes them to be synonymous also, as does Bermúdez (1961).

The holotypes of both *G. larmei* Akers and *G. obesa* Akers were examined, as well as specimens of both species sent by W. H. Akers. *G. larmei* seems to be synonymous with *G. debiscens*, although the specimens are smaller. *G. obesa* is similar but differs in having a less flattened evolute side and chambers which increase more rapidly in size as added. Another noticeable difference is seen when a specimen is placed on its flat evolute side; instead of the umbilical area being offset to the side as in *G. debiscens* it is facing symmetrically upward, so that the view is similar to that seen in one of the specimens of *G. debiscens* figured (Pl. 26, fig. 2), but this figured specimen has been tipped to show this view and is not lying naturally on its flat side. Like *G. debiscens*, *G. obesa* has an apertural face which curves down strongly on either side of the aperture. There seems to be a close relationship between the two species, and *G. obesa* may be only a variant form. For this reason it is placed tentatively in the synonymy of *G. debiscens*.

G. debiscens occurs in the core sequences part way up into Zone N.18. If the "flattened" form of *G. venezuelana* is included in *G. debiscens*, as some workers may decide, the range would extend into the basal part of Zone N.19.

Globoquadrina dutertrei (d'Orbigny)

Pl. 25, fig. 7

Globigerina rotundata d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 277, No. 6 (*nomen nudum*).

Globigerina dutertrei d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminifères," p. 84, pl. 4, figs. 19-21.

Globigerina rotundata d'Orbigny, Fornasini, 1898, Palaeontographia Italica, vol. 4, p. 208, text fig. 3.

Globigerina eggeri Rhumbler, 1901, in Brandt, Nordisches Plankton, Lief 1, No. 14, p. 19, text fig. 20 (after Brady, 1884, pl. 79, fig. 17, "*G. dubia* Egger").

Globigerina subcretacea Lomnicki, 1901, Naturf. Ver. Berlin, Band 39 (1900) Abh., p. 17 [included in synonymy: Brady, 1884, pl. 82, fig. 10, "*G. (cretacea* d'Orbigny?)"].

Globigerina dutertrei d'Orbigny, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 11, pl. 2, fig. 1 (lectotype).

Globigerina eggeri Rhumbler, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 11, pl. 2, fig. 4 (lectotype).

Globigerina rotundata Fornasini, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 19, pl. 2, fig. 2 (lectotype).

Globoquadrina dutertrei (d'Orbigny), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 242, pl. 7, figs. 1-13; pl. 8, figs. 1-4.

The concept of *G. dutertrei* is the same as that of an earlier study (Parker, 1962), and the reader is referred to the discussion and illustrations in that paper, where an attempt was made to illustrate the range of variation of the species. Only one specimen (inadvertently chosen from an Atlantic assemblage) is figured here, showing a typical specimen of an "advanced" type. Parker's (1962) illustrations include specimens with umbilical-extraumbilical apertures resembling *G. humerosa* (*q.v.*), the ancestral form. Some adults and most juveniles have such apertures, although the adults are usually more umbilicate than are specimens of *G. humerosa*. Many adult specimens, however, have an umbilical aperture and many show the typical globoquadrine teeth (see also the discussion under the genus *Globoquadrina*). *G. dutertrei* is similar in many ways to *G. altispira* but has a much lower spire than that species.

I am grateful to J. L. Lamb, who many years ago first called my attention to some of the evolutionary stages leading to the development of *G. dutertrei*.

This species evolved from *G. humerosa* in Zone N.21. Typical assemblages of the modern type are not well developed until the lower Quaternary.

Globoquadrina hexagona (Natland)

Pl. 25, figs. 9, 10

Globigerina hexagona Natland, 1938, Univ. Calif., Scripps Inst. Oceanography, Bull. Tech. Ser., vol. 4, No. 5, p. 149, pl. 7, fig. 1.

Globoquadrina hexagona (Natland), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 244, pl. 8, figs. 5-13.

This species occurs in the core sections from Zone N.17 to Quaternary, although it is known to range lower in land sections. *G. suturi* (Bolli) is probably synonymous, as previously mentioned by Todd (1964) and Lipps (1964). Blow and Banner (1962) placed in the synonymy of *G. suturi*, *Globigerina globularis* of Batjes (1958, pl. 11, figs. 3, 5, not fig. 4). They reported *G. suturi* from the Oligocene of Tanganyika, and Batjes reported his form from the Oligocene of Belgium. It would be desirable to reanalyze this long ranging species for evolutionary changes. In the core sections it is not usually common.

Globoquadrina humerosa (Takayanagi and Saito)

Pl. 24, figs. 10, 11; Pl. 25, figs. 1-6

Globorotalia humerosa Takayanagi and Saito, 1962, Sci. Repts., Tohoku Univ., 2d ser. (Geology), Spec. vol., No. 5, p. 78, pl. 28, figs. 1, 2.

G. humerosa was described from the Nobori Formation, Shikoku, Japan, discussed earlier in this paper (see "Previous Work"), and specimens from this formation sent to me by T. Saito were used for comparison. Like *G. acostaensis*, this species has an umbilical-extraumbilical aperture, and, also like that species, some specimens have long apertural teeth. None has the complicated tooth structure typical of *G. acostaensis*, as seen in many assemblages. *G. humerosa* is more umbilicate than *G. acostaensis*, and the progressive development from one form to the other is discussed under that species.

"*Globigerina*" *globorotaloidea* Colom may be conspecific with *Globoquadrina humerosa*, in which case that species would have priority. It was described from the Vindobonian of Spain and, although many specimens were figured, none was designated as the holotype. Specimens sent to me by Dr. Colom resemble *G. humerosa*, but he did not indicate the locality or the age of the specimens. It seems best, therefore, to refer the present species to *G. humerosa*.

This species appeared in the core sections in Zone N.18; Banner and Blow (1967) reported it from near the top of Zone N.16 as discussed under *G. acostaensis* (*q.v.*). In Zone N.21 some specimens became large and may have up to seven chambers in the final whorl (Pl. 25, fig. 6). They also became increasingly umbilicate, and throughout Zone N.21 there is a

gradual shifting to a typical assemblage of *G. dutertrei*. In the same way that specimens similar to *G. acostaensis* appear in *G. humerosa* assemblages, specimens like *G. humerosa* occur in the *G. dutertrei* assemblages, together with the umbilicate specimens typical of *G. dutertrei*.

Several specimens have been figured in an attempt to show the range of variation of *G. humerosa*. It can be seen that the variation is widely ranging and similar to that illustrated in an earlier paper for *G. dutertrei* in the Recent (Parker, 1962), except that in this case the specimens mostly have an umbilical-extraumbilical aperture.

***Globoquadrina pseudofoliata*, n. sp.**

Pl. 27, figs. 1-3

Description.—Test large, lobulate, with a rounded periphery, often biconvex; chambers globular, inflated, increasing rapidly in size as added, about 20 in the adult, 4 in the final whorl, the final chamber sometimes reduced in size; sutures depressed; wall of adults finely pitted, much coarser in juvenile stages; aperture umbilical, with triangular umbilical teeth. Largest diameter up to 0.9 mm., greatest thickness up to 0.6 mm.

Holotype.—LSDH 78 P, 30-32 cm. Lat 4°31'S., long. 168°02'E., 3208 m; Pacific Ocean. Pliocene or lower? Pleistocene. USNM No. 643067.

Remarks.—Specimens of this species are similar in shape to *Globigerina foliata* Bolli (compared both to the holotype and to specimens sent to M. N. Bramlette by H. M. Bolli), but that species is a true globigerinid with a hispid wall; in addition, *G. foliata* has chambers which increase more rapidly in size as added, lacks the globoquadrine umbilical teeth, and is much smaller in size. *Globoquadrina pseudofoliata* is more compressed, the chambers more globular and increasing more rapidly in size as added than in either *G. conglomerata* or *G. venezuelana*, to which species it seems most closely affiliated. The adults are distinctive and easily distinguished from adults of either of these species. *G. pseudofoliata* shows little variation except for the frequent reduction in size of the final chamber.

This species apparently branched off from *G. venezuelana* at the base of Zone N.19. In CAP 38 BP it seems to alternate in a few samples with that species, but this is not the case in LSDH 78 P, in which it occurs with *G. venezuelana* commonly in several samples. It is impossible, however, to differentiate the early stage juveniles of *G. pseudofoliata* from those of *G. venezuelana*. The flattened spiral side and sharp periphery differentiate later juveniles of this new species from those of *G. hexagona*, which they

somewhat resemble. The figured early stage (Pl. 27, fig. 2) was dissected from an adult to make certain of its identity. This specimen has heavy secondary spines which have not been seen in adults or in undissected early stages.

This species appeared in the core section near the base of Zone N.19 and probably became extinct in the lower part of the Quaternary, although this is not sure because of the uncertainty about what part of the Quaternary is represented near the tops of cores. The evidence from CAP 38 BP, however, suggests this possibility.

Globoquadrina venezuelana (Hedberg)

Pl. 26, figs. 4-10

Globigerina venezuelana Hedberg, 1937, Jour. Paleont., vol. 11, p. 681, pl. 92, fig. 7.

In the original description of this species, Hedberg in his synonymy compared this species with *Globigerina* sp. (?) of Cushman and Jarvis (1930), and placed questionably in the synonymy *Globigerina* cf. *G. apertura* Cushman of Nuttall (1932). These specimens have not been seen but the figures of the first certainly resemble this species; those of the second cannot be identified with any certainty.

G. venezuelana was discussed to some extent under *G. conglomerata*, to which it is ancestral. It is a somewhat variable species in the cores and, as in all of this group of *Globoquadrina* (including *G. conglomerata*, *G. pseudofoliata*), the early stages (Pl. 26, figs. 6-8) do not closely resemble the adults. The main differences between this species and *G. conglomerata* are the more compact test and smaller umbilical opening.

It is noticeable in the species mentioned above (i.e. *venezuelana*, *conglomerata*, *pseudofoliata*) that the pre-adult stages are much less high than adults and have a tendency, especially in *G. venezuelana*, to have a flattened apertural face somewhat similar to that of *G. debiscens*, but without the downward-curving apertural face on either side of the aperture that is usually seen in young stages of that species (see Pl. 26, fig. 2). Some of the specimens of *G. venezuelana* have a flattened spiral side rather like that of *G. debiscens* (see Pl. 26, figs. 6, 7, 9). In speaking here of young stages, I refer to pre-adult stages rather than to the much younger stages, which all resemble to a greater or lesser extent the juveniles of *G. conglomerata* figured by Parker (1962, pl. 6, figs. 15, 17, 18).

G. venezuelana occurs throughout the core sequences, changing gradually to *G. conglomerata* in the upper part of Zone N.21 and the basal Quaternary.

Genus **PULLENIATINA** Cushman, 1927

This species is placed tentatively in the Family Catapsydracidae. Various authors have given varying opinions, and a study of the young stages of the species does not give conclusive evidence for its origin. Lipps (1966) put the genus in the Globigerinidae, maintaining that the early chambers are spinose. This is true but the spines are often broad and may be the result of secondary deposition. Banner and Blow (1967), on the other hand, tentatively postulated that the genus developed from *Globobulimina acostaensis* ("*Globobulimina* (*Turbobulimina*)" of Banner and Blow, 1967). They pointed out, however, that the apertural position in juvenile *Pulleniatina primalis* (the parent species of the genus) is more ventral and that the ventral side is more convex than in *G. acostaensis*. They stated that both forms possess the same type of "granular" wall surface. The walls are not exactly similar, though, because while *G. acostaensis* has a pitted wall, *Pulleniatina* juveniles are more apt to have a rough wall with short stubby spines. Occasional specimens are seen, however, with what looks like a pitted wall structure. Adults have thick walls, with either a smooth, matte surface often seen in early *P. primalis*, or the smooth, polished surface of *P. obliquiloculata* and *P. spectabilis*.

The characteristics of this genus have been exhaustively discussed by Banner and Blow (1967). They have dissected specimens and analyzed the geometry of the streptospiral coiling in great detail.

Pulleniatina obliquiloculata (Parker and Jones)

Pl. 28, fig. 1

Pullenia obliquiloculata Parker and Jones, 1862, in Carpenter, *Introduction to the Study of the Foraminifera*, Ray Soc., p. 183 (*nomen nudum*).

Pullenia sphaeroides (d'Orbigny) var. *obliquiloculata* Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., vol. 155, p. 365, 368, pl. 19, fig. 4.

Pullenia sphaeroides (d'Orbigny) var. *obliquiloculata* Parker and Jones, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 25, pl. 7, fig. 4 (lectotype designated by Bolli *et al.*, 1957).

Globigerina antillensis Bermúdez, 1961, Bol. Geología, Pub. Esp. No. 3; Mem. Terc. Congr. Geol. Venezolano, tom. 3, p. 1.156, pl. 1, fig. 1.

Pulleniatina obliquiloculata (Parker and Jones), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 234, pl. 4, figs. 13-16, 19, 22.

Pulleniatina obliquiloculata (Parker and Jones) *trochospira* Hartono, 1964, Bull. Geol. Sur., Indonesia, vol. 1, No. 1, p. 10, text figs. a-c.

Pulleniatina obliquiloculata obliquiloculata (Parker and Jones, 1865) emended, Banner and Blow, 1967, Micropaleont., vol. 13, No. 1, p. 137, pl. 3, fig. 4 (lectotype refigured); pl. 4, fig. 9.

Pulleniatina obliquiloculata (Parker and Jones) *finalis*, Banner and Blow, 1967, Micropaleont., vol. 13, No. 1, p. 140, pl. 2, figs. 4-10; pl. 3, fig. 5; pl. 4, fig. 10.

Banner and Blow (1967) gave a detailed discussion of this species and its evolution from *P. primalis*. Besides the subspecies listed in the synonymy, they described *P. obliquiloculata praecursor*. This form has been included with *P. primalis* in this paper and is further discussed under that species, with some doubt as to the present interpretation of these two species (*P. primalis* and *P. obliquiloculata*) as discrete forms occurring simultaneously during part of their ranges. The two species, *P. primalis* and *P. obliquiloculata*, are here divided according to the presence or absence of a "linear suture" (a single suture formed by the meeting of the final two sutures prior to reaching the umbilical area), a rather arbitrary distinction. The end point of the evolutionary series, *P. obliquiloculata finalis*, has not been considered here because the Quaternary has not been differentiated.

P. J. Bermúdez has sent me specimens of his *Globigerina antillensis*, which are young specimens referable to *P. obliquiloculata* (as also noted by Banner and Blow, 1967). Specimens of Hartono's "variety" have not been seen but are almost certainly referable to *P. obliquiloculata*, as stated by Banner and Blow (1967), who discussed the species so fully that no further descriptive remarks will be given here. *P. obliquiloculata* developed from *P. primalis* in the lower part of Zone N.19 in the Indo-Pacific core sections; Banner and Blow (1967) placed the beginning of this species (as interpreted in this paper) higher in this zone.

***Pulleniatina primalis* Banner and Blow**

Pl. 27, figs. 5, 6

Pulleniatina semiinvoluta Parker (not Germeraad, 1946), 1965, Contr. Cushman Found. Foram. Res., vol. 16, p. 151, text figs. 5, 6.

Pulleniatina primalis Banner and Blow, 1967, Micropaleont., vol. 13, No. 1, p. 142, pl. 1, figs. 3-8; pl. 3, fig. 2.

Pulleniatina obliquiloculata (Parker and Jones) *praecursor* Banner and Blow, 1967, Micropaleont., vol. 13, No. 1, p. 139, pl. 3, fig. 3.

This species in the earlier part of its range has a matte wall, which higher in the section becomes somewhat polished. The intercameral sutures extend into the umbilicus without forming a "linear suture" (*i.e.*, meeting before reaching the umbilical area to form a single suture which extends into the umbilical area) described by Banner and Blow. The early specimens are evolute and convex dorsally and the sutures are depressed, but in the phylogenetically younger specimens the dorsal sutures are less depressed and the dorsal side somewhat flattened. These characteristics and additional ones are fully discussed by Banner and Blow in their description of this species. "*P. obliquiloculata praecursor*" is included here because it has no

"linear suture". Whether or not *P. primalis* and *P. obliquiloculata* are discrete species occurring together during part of their ranges as considered here is somewhat questionable. We may rather have an evolutionary series *P. primalis* to *P. obliquiloculata* (including variable forms with and without a linear suture) to *P. obliquiloculata* (less variable with no specimens lacking a linear suture).

P. primalis occurs in the cores from Zone N.17 to about the middle of Zone N.21.

***Pulleniatina spectabilis* Parker**

Pl. 28, fig. 2

Pulleniatina spectabilis Parker, 1965, Contr. Cushman Found. Foram. Res., vol. 16, p. 151, text figs. 1-4.

Pulleniatina spectabilis Parker, Banner and Blow, 1967, Micropaleont., vol. 13, p. 143, pl. 2, figs. 2, 3.

This species is easily identified by its almost plano-convex test, and broad pseudocarina. Although some specimens appear to be keeled, the periphery is merely pinched to an acute angle. The species started to evolve from *P. primalis* near the top of Zone N.18, became typical in lower Zone N.19, and ranges up to Zone N.21 (at least in cores lacking Zone N.20). It has been found only in three cores thus far: CHUB 30 (Zone N.19/N.20), CAP 38 BP (upper Zone N.19, and basal N.21), and LSDH 78 P (upper Zone N.18 and basal Zone N.19). In LSDH 78 P the specimens are not typical until more than 200 cm above the base of Zone N.19. The N.18 and basal N.19 specimens have nearly plano-convex tests but have not yet developed the characteristic pseudocarinae.

Family GLOBOROTALIIDAE Cushman, 1927

This family includes trochoid genera having smooth walls, with or without coarse secondary spines. The genera are nonspiny when living, may be coarsely or finely perforate, and have angular or ovate chambers. The Candeininae, placed in the Globorotaliidae by Lipps (1966), has been raised to family status here. He included the genus *Turborotalita* in that family, as has been done here, but it is possible that this genus should be retained in the Globorotaliidae. Nothing is known of its antecedents. The Candeinidae are excluded because, unlike the globorotaliids, they have globular or nearly globular chambers, are always finely perforate, and are almost invariably smooth, although fine secondary spines sometimes occur. They do not tend to become increasingly thick-walled during life as do the globorotaliids.

Genus **GLOBOROTALIA** Cushman, 1927

Globorotalia and *Turborotalia* are considered to be synonymous because turborotalian species appear to have been ancestral to several lineages which develop keeled forms. Some of these lineages may be generically separable, but for this separation new generic criteria must be set up. Also, it will be necessary to trace the evolutionary sequences much farther back in geologic time than has been done in the present study. Some seemingly keeled species do not have nonporous, canaliculate keels such as are seen in the type species of this genus, *Globorotalia tumida*, but rather have sharply angled peripheries. Such false keels are seen for example in specimens of *Globorotalia margaritae*.

The pitted-wall species listed under this genus as "Group 3" by Parker (1962) are excluded from this genus. Most of them probably belong in the family of Catapsydracidae.

Globorotalia anfracta, n. sp.

Pl. 28, figs. 3-8

Description.—Test small, early part flattened on the evolute side, later chambers becoming increasingly convex, periphery rounded; chambers subquadrate, inflated, increasingly so as added, $4.5\frac{1}{2}$ in the final whorl, up to 13 in all, usually 10-11 in all; sutures narrow, depressed, curving; wall thin, smooth, translucent, finely perforate; aperture highly arched, often extending up onto the periphery, with a relatively broad lip. Diameter up to about 0.25 mm, usually smaller.

Holotype.—CHUB IV G, 0-3 cm. Lat. $13^{\circ}35'N.$, long. $91^{\circ}35'W.$, 119 m; Pacific Ocean. Recent. USNM No. 643076.

Remarks.—*G. anfracta* differs from *G. scitula* in the more broadly rounded periphery, more highly arched aperture, dorsally inflated later chambers, lack of ornamentation by secondary spines, and smaller size.

This species is described from a Recent sample in which it is much more common than in the fossil core material. It is common also in plankton samples from the Gulf of California.

The ancestry is not known, probably because of the elimination of many small species from the cores by solution of calcium carbonate.

G. anfracta first occurs in the cores near the base of Zone N.21, but may be found lower in the section at some later time.

Globorotalia cibaoensis Bermúdez

Pl. 29, figs. 4-6

Globorotalia cibaoensis Bermúdez, 1949, Cushman Lab. Foram. Res., Spec. Pub. 25, p. 285, pl. 22, figs. 21-23.

Globorotalia scitula Bolli (not *Pulvinulina scitula* Brady, 1882), 1957, U. S. Nat. Mus., Bull. 215, p. 120, pl. 29, figs. 11, ?12.

Core specimens agree well with the holotype and paratypes from the U. S. National Museum. This species is variable in the amount of angulation of the periphery, especially of the later chambers. Some specimens appear to have a narrow keel, which, however, is noncanaliculate, according to the section of an apparently keeled specimen from CAP 38 BP, 860-862 cm. Specimens referred to *G. scitula* and sent to M. N. Bramlette by H. M. Bolli apparently are synonymous with *G. cibaoensis*. The specimens figured by Bolli as *G. scitula* were examined also, and his first figured specimen (fig. 11) seems certainly referable to *G. cibaoensis*. *G. cibaoensis* may be identical or closely related to *G. miozea* Finlay, but this is not provable from topotypes sent by D. G. Jenkins.

This species occurs throughout the section studied up to the base of Zone N.19 where apparently it developed into *G. crassula*. It is found only in CAP 38 BP and in one sample from LSDA 101 G. It is very common in the Lamont core V3-153, from the Blake Plateau.

***Globorotalia crassaformis* (Galloway and Wissler)**

Pl. 30, figs. 1-3

Pulvinulina crassa Brady (not *Rotalina crassa* d'Orbigny, 1840), 1884, Rept. Voy. Challenger, Zoology, vol. 9, p. 694, pl. 103, figs. 11, 12.

Globigerina crassaformis Galloway and Wissler, 1927, Jour. Paleont., vol. 1, p. 41, pl. 7, fig. 12.

Globorotalia (*Turborotalia*) *oceanica* Cushman and Bermúdez, 1949, Contr. Cushman Lab. Foram. Res., vol. 25, p. 43, pl. 8, figs. 13-15.

Globorotalia punctulata Phleger, Parker, and Peirson (not *Globigerina punctulata* Deshayes, 1832), 1953, Repts. Swedish Deep-Sea Exped., vol. 7, fasc. 1, p. 20, pl. 4, figs. 8-12.

Globorotalia crassaformis (Galloway and Wissler), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 235, pl. 4, figs. 17, 18, 20, 21.

This species is variable in the cores. The chief variation is in the sharpness of the periphery, forms with a rounded periphery being the most common, although the early stages often have an angled periphery. There is variation also in the outline of the periphery, some specimens (Pl. 30, fig. 1) having the typical angled outline, whereas others (Pl. 30, figs. 2, 3) are almost circular to an extent not observed in Recent Pacific material.

The lowest occurrence is near the base of Zone N.19 in CAP 38 BP. This occurrence seems to be in accord with published data, but W. H. Blow (personal communication) believes that the species appeared earlier. That it appeared in the Pacific core with no hint of its derivation rather bears

this out. It seems possible that *G. crassaformis*, which is presently more common between lats. 25-35°S., developed earlier at those latitudes than in the tropical area. Kennett (1966) hypothesized its development from *G. miozea* Finlay near the Miocene-Pliocene boundary in New Zealand. As mentioned previously, the correlation of this boundary with the present one is not certain.

This species is the ancestor of the *G. crassaformis*-*G. tosaensis*-*G. truncatulinooides* lineage (see discussions under the other two species).

Globorotalia crassula Cushman and R. E. Stewart Pl. 29, figs. 2, 7

Globorotalia crassula Cushman and R. E. Stewart, 1930, San Diego Soc. Nat. Hist., Trans., vol. 6, p. 77, pl. 7, fig. 1.

Globorotalia hirsuta Parker (part) (not *Rotalina hirsuta* d'Orbigny, 1839), 1962, p. 236, pl. 5, figs. 13, 15 (these are specimens referred to as "group 3") (not pl. 5, figs. 10-12, 14; pl. 6, fig. 1).

Cushman and R. E. Stewart put Brady's "*Pulvinulina crassa*" from the *Challenger* material in the synonymy of their species. That form, however, is referable to *Globorotalia crassaformis*. Core and Recent Pacific specimens agree well with the holotype of *G. crassula*, which unfortunately is not a good specimen. This species is believed to have developed from *G. cibaoensis*, and there is evidence for this evolution in CAP 38 BP, although it is not fully demonstrated. *G. crassula* differs from *G. cibaoensis*, which it resembles closely, in being plano-convex, and in having 4-4½ chambers in the final whorl (*G. cibaoensis* usually has 4½-5, occasionally 4).

G. crassula is seen in Zone N.19 sparsely, first occurring at the base of the zone. It is more common in Zone N.21 and the Quaternary, especially the latter, perhaps because of the presence of cooler water than was found in the tropical area earlier.

Globorotalia cultrata (d'Orbigny) Pl. 31, figs. 2, 3

Rotalia (*Rotalia*) *menardii* d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 273, No. 26; Modèles No. 10, 1re livraison (*nomen nudum*).

Rotalia limbata d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 274, No. 30 (*nomen nudum*).

Rotalia nitida d'Orbigny, 1826, Ann. Sci. Nat., sér. 1, vol. 7, p. 274, No. 31 (*nomen nudum*).

Rotalina (*Rotalina*) *cultrata* d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminifères", p. 76, pl. 5, figs. 7-9.

Rotalia limbata Fornasini, 1902, R. Accad. Sci. Ist. Bologna, Mem. Sci. Nat., ser. 5, vol. 10, p. 56, text fig. 55.

Rotalia nitida Fornasini, 1906, R. Accad. Sci. Ist. Bologna, Mem. Sci. Nat., ser. 6, vol. 3, p. 66, pl. 3, fig. 4.

Rotalia menardii Parker, Jones, and Brady, 1865, Ann. Mag. Nat. Hist., vol. 16, ser. 3, p. 20, pl. 3, fig. 81.

- Rotalia limbata* Fornasini, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 30, pl. 5, fig. 3 (lectotype).
Rotalia menardii Parker, Jones, and Brady, Banner and Blow, Contr. Cushman Found. Foram. Res., vol. 11, p. 31, pt. 6, fig. 2 (lectotype).
Rotalia nitida Fornasini, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 33, pl. 6, fig. 3 (lectotype).
Rotalina cultrata d'Orbigny, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 34, pl. 6, fig. 1 (lectotype).
Globorotalia cultrata (d'Orbigny), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 235, pl. 5, figs. 3-5 (Pessagno, 1964, demonstrated by form analysis that these figures represent *G. tumida*. The specimens have not been restudied).

This species is mostly left coiling in the cores. It is rare in the lower part of the section studied and is sometimes difficult to differentiate from *G. multicamerata*, a species which evolved much later than *G. cultrata*. *G. cultrata* has fewer chambers in the final whorl, the chambers are broader, in relation to their height (as is also true in comparison with the chambers of *G. tumida*), and the test is usually more elongate.

Globorotalia fimbriata (Brady)

Pl. 31, fig. 4

- Pulvinulina menardii* (d'Orbigny) var. *fimbriata* Brady, 1884, Rept. Voy. Challenger, Zoology, vol. 9, p. 691, pl. 103, fig. 3 (lectotype).
Pulvinulina menardii (d'Orbigny) var. *fimbriata* Brady, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 25, pl. 5, fig. 2 (after Brady, 1884).
Globorotalia fimbriata (Brady), Hofker, 1956, Spolia Zoologica Musei Hauniensis, vol. 15, p. 194, pl. 30, figs. 7-14.

Hofker appears to have been the first to raise this form to species status and presented his reasons for so doing lucidly. The species is easily differentiated from others by its white glistening wall and the inflation of the chambers towards the umbilicus. The core specimens have mostly lost the carinal spines by corrosion or erosion. *G. fimbriata* appeared near the base of Zone N.21, apparently developed from *G. cultrata*, although the evolution is not clearly demonstrated.

Globorotalia hirsuta (d'Orbigny)

Pl. 32, fig. 3

- Rotalina hirsuta* d'Orbigny, 1839, in Barker-Webb and Berthelot, Hist. Nat. Iles Canaries, "Foraminifères", vol. 2, pt. 2, p. 131, pl. 1, figs. 37-39.
Globorotalia hirsuta (d'Orbigny), Parker, 1962 (part), Micropaleont., vol. 8, No. 2, p. 236, pl. 5, figs. 10, 11, 12, 14 (not figs. 13, 15); pl. 6, fig. 1.

The species concept here is the same as that of Parker (1962) except that the "group 3" specimens are referred to *G. crassula*. Banner and Blow (1967) postulated the development of the typical form of *G. hirsuta* from *G. margaritae*, through an intermediate stage, in the lower Quaternary. This development is weakly demonstrated in the core material but

apparently occurs near the base of Zone N.20 or N.21, because typical specimens occur in Zone N.21 in Indian Ocean cores. Some intermediate forms referred by Banner and Blow (1967) to "*G. (G.)* sp. aff. *hirsuta*" are here referred to *G. margaritae*, according to the identification of a specimen from CAP 38 BP, 528-530 cm (Zone N.19) by W. H. Blow (personal communication). *G. hirsuta* differs from *G. margaritae* in having a much larger, more thick-walled test.

G. hirsuta is rare, occurring mostly in the Indian Ocean cores.

***Globorotalia inflata* (d'Orbigny)**

Pl. 29, figs. 1, 3

Globigerina inflata d'Orbigny, in Barker-Webb and Berthelot, 1839 Hist. Nat. Iles Canaries, "Foraminifères", vol. 2, pt. 2, p. 134, pl. 2, figs. 7-9.

Globorotalia sp. 1 Phleger, Parker, and Peirson, 1953, Repts. Swedish Deep-Sea Exped. 1947-1948, vol. 7, fasc. 1, p. 23, pl. 4, figs. 19-21.

Globorotalia inflata (d'Orbigny), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 236, pl. 5, figs. 6-9.

Globorotalia sp. 1 Ericson, Ewing, and Wollin, 1964, *Science*, vol. 146, No. 3645, p. 728.

G. puncticulata (Deshayes) may be a variant form of *G. inflata*, in which case it would have priority. It differs chiefly in its more lobulate test. Another variant form (Pl. 29, fig. 3) is that which Phleger, *et al.* and later Ericson, *et al.* called *G. sp. 1*. This variant is common in the Indian Ocean cores but was not observed in the Pacific cores. It has a flat evolute side and is much larger than typical. Core specimens of *G. inflata* are usually thick-walled and smooth, with the usual secondary spines in the umbilical area.

McInnes (1965) and Walters (1965) postulated the development of this species from *G. miozea* Finlay near the New Zealand Miocene-Pliocene boundary. The precise correlation of this boundary with that used in this paper is not known. *G. inflata* (and variant) appeared in Zone N.21 and occurs mostly in the Indian Ocean cores. It is suggested that the species probably appeared earlier at higher latitudes and did not penetrate the tropical area until the water was sufficiently cooled by increasing glaciation. This suggestion is borne out by its presence in samples from the Tabianian beds (lower Pliocene) sent to me by M. Cardello Chierici.

***Globorotalia margaritae* Bolli and Bermúdez**

Pl. 32, figs. 1, 2

Globorotalia margaritae Bolli and Bermúdez, 1965, Bol. Inform. Asoc. Venezolana, Geología, Minería y Petróleo, vol. 8, No. 5, p. 139, pl. 1, figs. 16-18.

Specimens, including topotypes, were sent to me by both authors. A section of one of the topotypes shows that the keel is formed by the sharply angled periphery and is not canaliculate. Included here with this species are forms referred by Banner and Blow (1967) to their *G. aff. G. hirsuta*. Discussion of the evolution of *G. margaritae* to *G. hirsuta* will be found under the latter species. In the cores *G. margaritae* occurs from near the top of Zone N.18 up into Zone N.20, but it is rare and occurs in too few cores to be sure that this range is an accurate one.

Globorotalia merotumida Banner and Blow

Pl. 32, fig. 4

Globorotalia (G.) merotumida Banner and Blow, 1965, Nature, vol. 207, No. 5004, p. 1352 (p. 3 of reprint), text fig. 1.

This species, like "*G. tumida plesiotumida*" (see *G. tumida*), is difficult to define and identify with assurance. Thus, confusion may result from the differing views of workers dealing with biostratigraphic problems. The specimen figured here was identified as a typical form of the species by W. H. Blow. Specimens are so rare in the core sections that nothing can be learned about the range of variation and no opinion can be given about the authenticity of the species.

Specimens possibly referable to *G. merotumida* occur in Zone N.16 and range up to the base of Zone N.18.

Globorotalia multicamerata Cushman and Jarvis

Pl. 31, figs. 5, 6

Globorotalia menardii (d'Orbigny) var. *multicamerata* Cushman and Jarvis, 1930, Jour. Paleont., vol. 4, p. 367, pl. 34, fig. 8.

Globorotalia menardii (d'Orbigny) var. *fijiensis* Cushman, 1934, Bernice P. Bishop Mus., Bull., No. 119, p. 136, pl. 17, fig. 5.

Core specimens compare well both with topotypes and with specimens from Fiji. This species has narrower chambers and a more circular outline than *G. cultrata*. It is usually right coiling although there are occasional shifts to left coiling, for example at 631-633 cm in CAP 38 BP, in Zone N.18. Little attention has been paid to coiling-direction changes in this paper because the wide area covered makes their use in correlation impractical and dangerous. Young specimens are sometimes difficult to separate from *G. cultrata*, but for the most part the species are distinct. Adult specimens may have up to about 9½ chambers in the final whorl.

G. multicamerata occurs in the cores from Zone N.17 up into the lower part of Zone N.21. It is common in many samples.

Globorotalia scitula (Brady)

Pl. 27, fig. 7

Pulvinulina scitula Brady, 1882, Roy. Soc. Edinburgh, Proc., vol. 11 (1880-82), No. 111, p. 716.

Pulvinulina patagonica d'Orbigny sp., Brady, 1884 (not *Rotalina patagonica* d'Orbigny, 1839), Rept. Voy. *Challenger*, Zoology, vol. 9, p. 693, pl. 103, fig. 7.

Pulvinulina scitula Brady, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 27, pl. 5, fig. 5 (lectotype).

Globorotalia scitula (Brady), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 238, pl. 6, figs. 4-6.

This species occurs widely in many samples but is never common. This scarcity is to be expected from its distribution in modern sediments in the South Pacific, where occurrences are scattered north of lat. 25°S. (Parker, 1962). *G. scitula* is found throughout the section from Zone N.17.

Globorotalia tosaensis Takayanagi and Saito

Pl. 30, figs. 4-7

Globorotalia tosaensis Takayanagi and Saito, 1962, Sci. Repts. Tohoku Univ., ser. 2 (Geology), Spec. vol. No. 5, p. 81, pl. 28, figs. 11, 12.

Core specimens agree well with topotypes sent by T. Saito. It was thought at first that this species represented "buried-keel" *G. truncatulinoides* but sectioning proves that this is not the case. In addition, some specimens are relatively thin-walled, and the rounded, porous periphery can be plainly seen. This species developed from *G. crassaformis* at the base of Zone N.21 (by zone definition. The possibility of its appearance lower in the section at higher latitudes has been discussed elsewhere in this paper). A paper recently obtained from T. Huang (1966) postulated this evolution also. *G. tosaensis* differs from the rounded-periphery form of *G. crassaformis* in having five chambers in the final whorl, a slightly more angled periphery, and more curving sutures. There is little difficulty in seeing in the cores the demarcation between the two species. Transitional specimens show more lobulation than those figured here. The further evolution to *G. truncatulinoides* is harder to pinpoint.

G. tosaensis occurs in Zone N.21 and seemingly was completely changed into *G. truncatulinoides* near the base of the Quaternary. The two species are plotted together for about 70 cm of CAP 38 BP (Table 2), but it is probable that this section reflects an evolutionary transitional period.

Globorotalia truncatulinoides (d'Orbigny)

Pl. 31, fig. 1

Rotalina truncatulinoides d'Orbigny, 1839, in Barker-Webb and Berthelot, Hist. Nat. Iles Canaries, "Foraminifères", vol. 2, pt. 2, p. 132, pl. 2, figs. 25-27.

This species developed from *G. tosaensis* at the base of Zone N.22 (by definition). Specimens were not referred to *G. truncatulinoides* until the canaliculate keel was well marked and discernible along the periphery of most of the test. In many evolutionary series the line of demarcation between species is not abrupt, and that is the case here. It is probable that in many cases no two workers would pick the exact same spot for the boundary line between the two, but, luckily, in the cores the sections are short and the evolutionary process happened relatively quickly. The evidence from the core sequences suggests that they truly reflect a valid evolutionary sequence. Possible evidence to the contrary is discussed earlier in this paper in the discussion of the Bolli and Bermúdez zonation.

Globorotalia tumida (Brady)

Pl. 32, figs. 5-7

Pulvinulina menardii (d'Orbigny) var. *tumida* Brady, 1877, Geol. Mag., new ser., dec. 2, vol. 4, No. 12, p. 535.

Pulvinulina tumida Brady, 1884, Rept. Voy. *Challenger*, Zoology, vol. 9, p. 692, pl. 103, figs. 4-6.

Pulvinulina tumida Brady var. *flexuosa* Koch, 1923, Eclogae Geol. Helvetiae, vol. 18 (1923-4), No. 2, p. 357, text figs. 9, 10.

Pulvinulina menardii (d'Orbigny) var. *tumida* Brady, Banner and Blow, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 26, pl. 5, fig. 1 (lectotype).

Globorotalia tumida (Brady), Parker, 1962, Micropaleont., vol. 8, No. 2, p. 239, pl. 6, figs. 8-10.

The type locality of this species is the same as that described under *Globigerinoides sacculifer*. Thus, the typical form is the one seen in the upper Miocene (Zone N.18). The flexuose form (Pl. 32, fig. 7) occurs also in the toptype assemblage and intermittently throughout the section, and gradation is shown to the typical form.

Rare specimens tentatively referable to "*Globorotalia* (*Globorotalia*) *tumida plesiotumida*" Banner and Blow occur in the lower part of CAP 38 BP, at 829-831 cm and possibly at 860-862 cm. This form is hard to recognize in the Pacific material and may prove difficult to identify by the usual subjective approach. Workers will differ considerably in their interpretations of a "subspecies" about whose range of variation nothing is yet known. *G. tumida* assemblages up to about 600 cm in CAP 38 BP include primitive specimens (Pl. 32, fig. 5) but typical ones identical in size and character to toptypes occur as low as 804 cm. (sample at 802-804 cm is not included in Table 2). For this reason the boundary of Zones N.17/N.18 is placed at this level. It is probable that at many localities this boundary will be difficult or impossible to define according to Banner and Blow's definition, because the environment was not suitable for typical *G. tumida*.

This species is commonly present throughout the core sequences from Zone N.18 up.

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PLATES

EXPLANATION OF PLATE 17

Figure	Page
1, 2. Candeina nitida d'Orbigny	145
Side views; X66. CAP Alexa-Penguin Bank, Tredge No. 2. USNM Nos. 642972, 642973.	
3-5. Globigerinita glutinata (Egger)	146
Fig. 3b, edge view; all others, side views; X93. CAP 38 BP; fig. 3, 674-676 cm; fig. 4, 400-410 cm; fig. 5, 579-582 cm. USNM Nos. 642974-642976.	
6, 7. Globigerinita tota Parker	146
Fig. 6b, edge view; all others, side views; X150. CAP 38 BP; fig. 6, 408-410 cm; fig. 7, 522-530 cm. USNM Nos. 642977, 642978.	
8, 9. Globigerinita uvula (Ehrenberg)	146
Figs. 8a, c, side views; 8b, 9, edge views; X150. CAP 38 BP, 674-676 cm. USNM Nos. 642979, 642980.	
10. Turborotalita humilis (Brady)	146
Figs. 10a, c, side views; fig. 10b, edge view; X150. CAP 38 BP, 528-530 cm. USNM No. 642981.	



1



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2 b



3 a



3 b



3 c



4



5



6 a



6 b



6 c



7



8 a



8 b



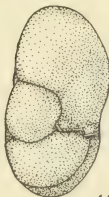
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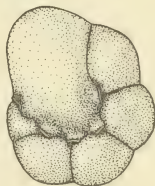
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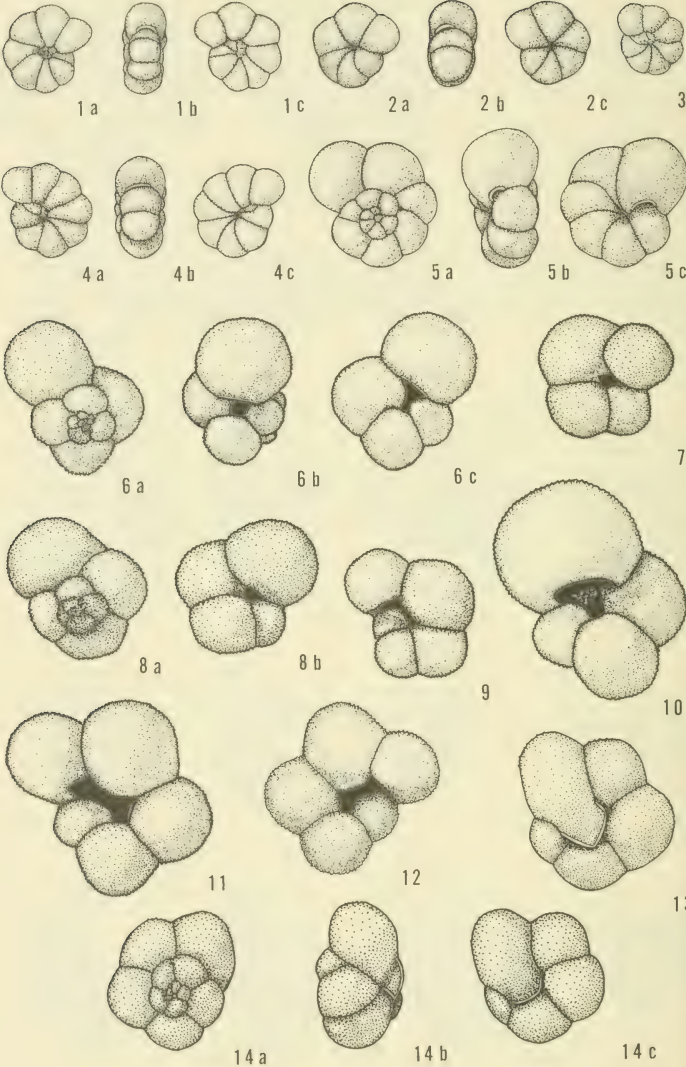
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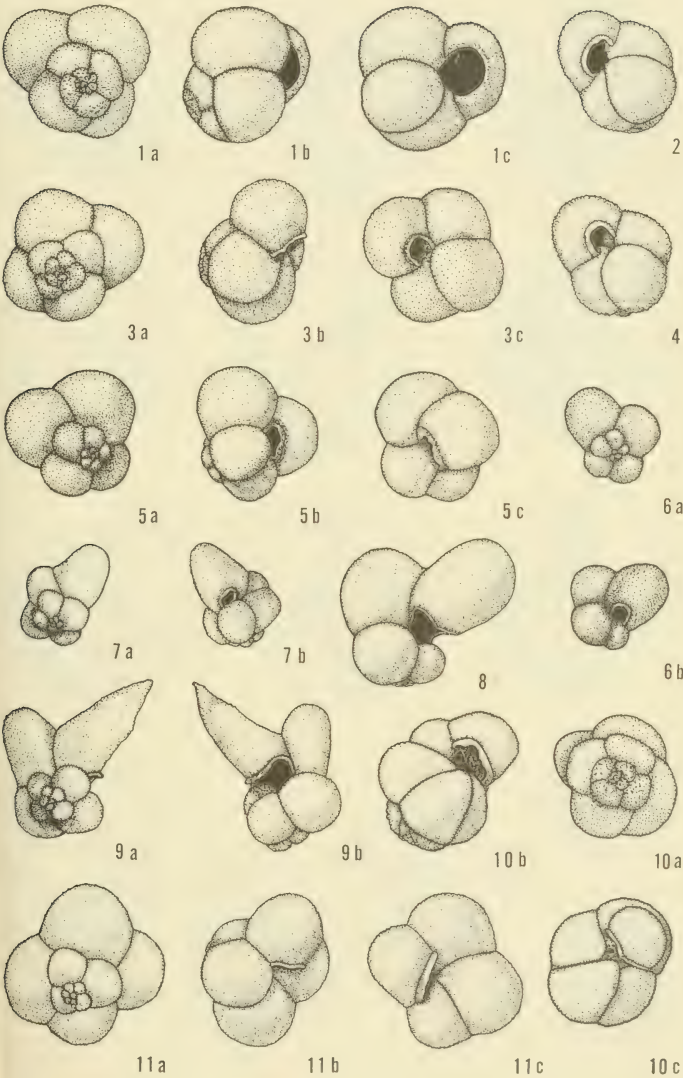


EXPLANATION OF PLATE 18

Figure	Page
1-4. <i>Globanomalina praepumilio</i> , n. sp.	148
Figs. 1b, 2b, 4b, edge views; all others, side views; X135. DODO 117 P, 164-166 cm. Fig. 1, holotype, USNM No. 642982; figs. 2-4, paratypes, USNM Nos. 642983-642985.	
5. <i>Globanomalina</i> (?) <i>pumilio</i> (Parker)	148
Figs. 5a-c, side views; fig. 5b, edge view; X135. CAP 41 HG, 0-1 cm (Recent; lat. 15°55.5'S., long. 117°13.8'W.; 3394m). USNM No. 642936.	
6-12. <i>Globigerina calida</i> Parker	149
Fig. 6b, edge view; all others, side views; fig. 6, X66; figs. 7-12, X52. Figs. 6-8, primitive; figs. 9, 10, 12, almost typical; fig. 11, typical. Fig. 6, CAP Alexo-Papua Bank, Dredge No. 2; figs. 7-11, CAP 38 BP; fig. 7, 674-676 cm, figs. 8-10, 249-250 cm, fig. 11, 0-10 cm; fig. 12, DODO 117 P 164-166 cm. USNM Nos. 642987-642993.	
13, 14. <i>Globigerina</i> cf. <i>G. quinqueloba</i> Natland	151
Fig. 14b, edge view; all others, side views; X135. CAP 38 BP, 145-150 cm. USNM No. 642994, 642995.	

EXPLANATION OF PLATE 19

Figure	Page
1, 2. Globigerina decoraperta Takayanagi and Saito	149
Figs. 1b, 2, edge views; all others, side views; X93. Fig. 1, CAP Alexa-Penguin Bank, Dredge No. 2; fig. 2, CAP 38 BP, 528-530 cm. USNM Nos. 642996, 642997.	
3, 4. Globigerina rubescens Hofker	152
Fig. 3b, edge view; all others, side views; X93. White specimens. CAP 38 BP, 408-410 cm. USNM Nos. 642998, 642999.	
5-8. Globigerina praedigitata , n. sp.	151
Fig. 5b, edge view; all others, side views; X52. Figs. 5-7, typical; fig. 8, transitional to <i>G. digitata</i> . Fig. 5, holotype, CAP 38 BP, 579-582 cm, USNM No. 643000; figs. 6-8, paratypes, CAP 38 BP: fig. 6, 528-530 cm, fig. 7, 579-582 cm, fig. 8, 408-410 cm. USNM Nos. 643001-643003.	
9. Globigerina digitata Brady	150
Side views; X52. CAP 38 BP, 0-10 cm. USNM No. 643004.	
10. Globigerina nepenthes Todd	150
Figs. 10a, c, side views; fig. 10b, edge view; X66. LSDH 78 P, 499-502 cm. USNM No. 643005.	
11. Globigerina falconensis Blow	150
Figs. 11a, c, side views; fig. 11b, edge view; X93. DODO 117 P, 108-110 cm. USNM No. 643006.	





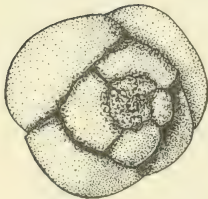
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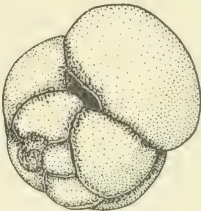
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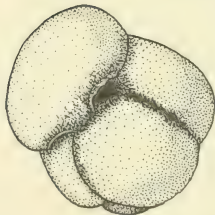
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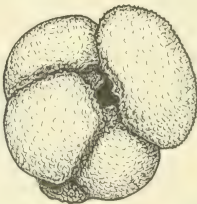
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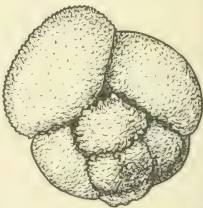
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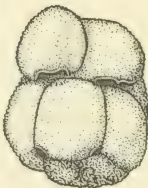
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6 a



6 b



6 c



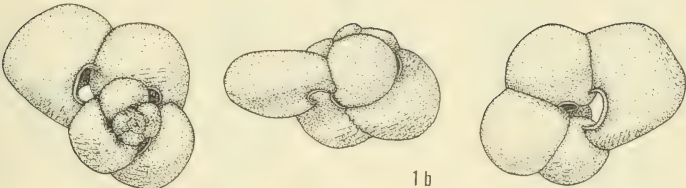
5 b

EXPLANATION OF PLATE 20

Figure	Page
1, 2. Globigerinoides bollii Blow	153
Side views; X95. CAP 38 BP; fig. 1, 860-862 cm; fig. 2, 630-633 cm. USNM Nos. 643007, 643008.	
3, 4. Globigerinoides conglobatus (Brady)	154
Fig. 3a, side view; all others, edge views; X52. CAP 38 BP; fig. 3, 860-862 cm; fig. 4, 579-582 cm. USNM Nos. 643009, 643010.	
5, 6. Globigerinoides obliquus Bolli	155
Figs. 5a, 6a, side views; all others, edge views; X66. LSDH 78 P, 299-302 cm. USNM Nos. 643011, 643012.	

EXPLANATION OF PLATE 21

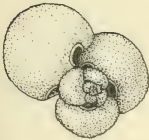
Figure	Page
1, 2, 4. Globigerinoides sacculifer (Brady)	156
Figs. 1b, 2b, 4b, edge views; all others, side views; X36. Figs. 1, 2, typical form; fig. 4, modern form. Figs. 1, 2, LSDH 78 P, 216-218 cm; fig. 4, CAP 38 BP, 145-150 cm. USNM Nos. 643013-643015.	
3, 5, 6. Globigerinoides fistulosus (Schubert)	154
Side views; X36. RIS 84 G, 42-44 cm. USNM Nos. 643016-643018.	



1 a

1 b

1 c



2 a



2 b



2 c



3



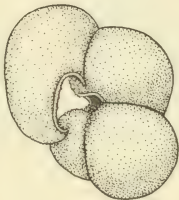
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4 b



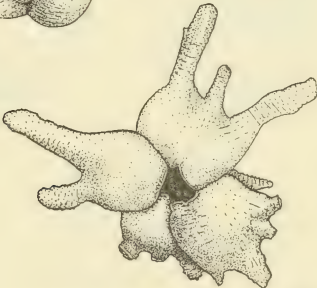
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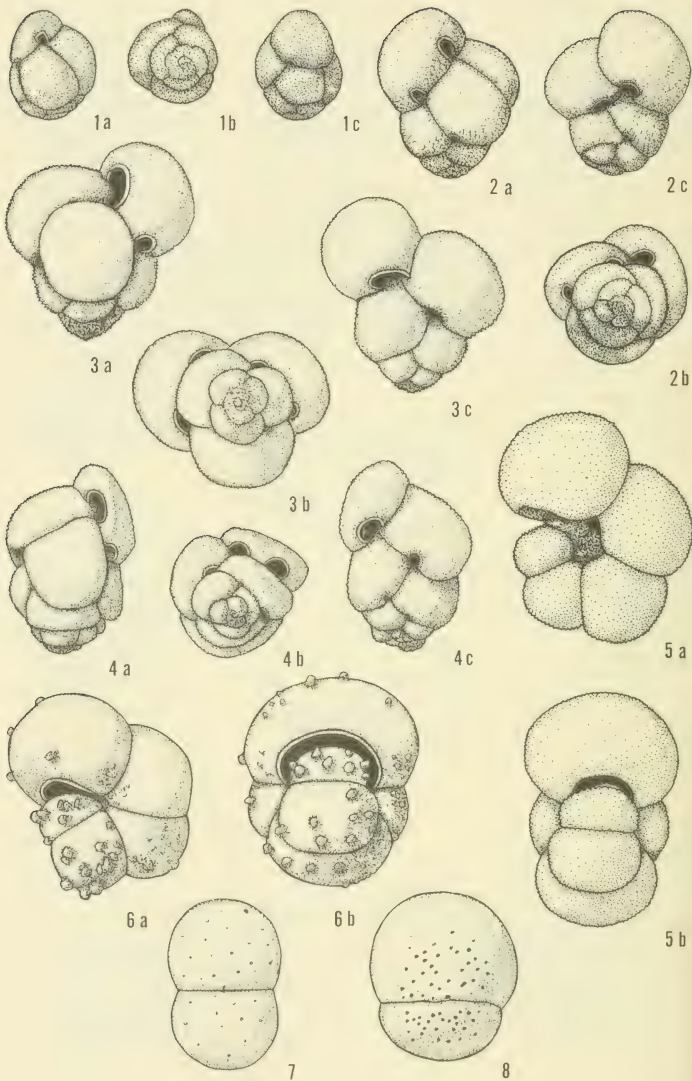
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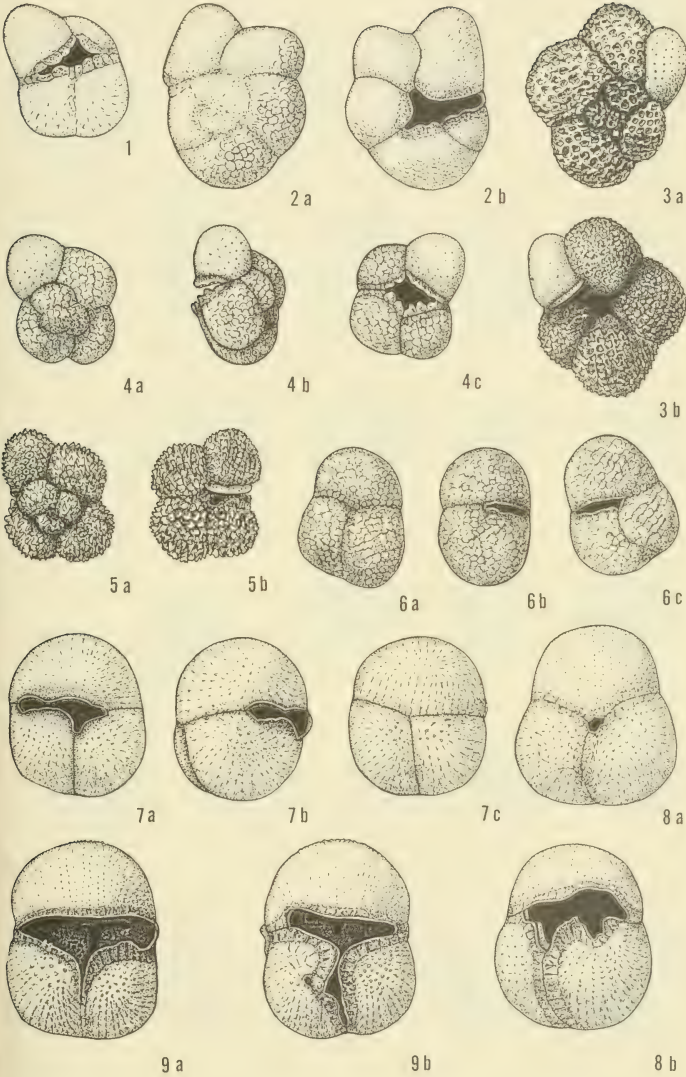
EXPLANATION OF PLATE 22

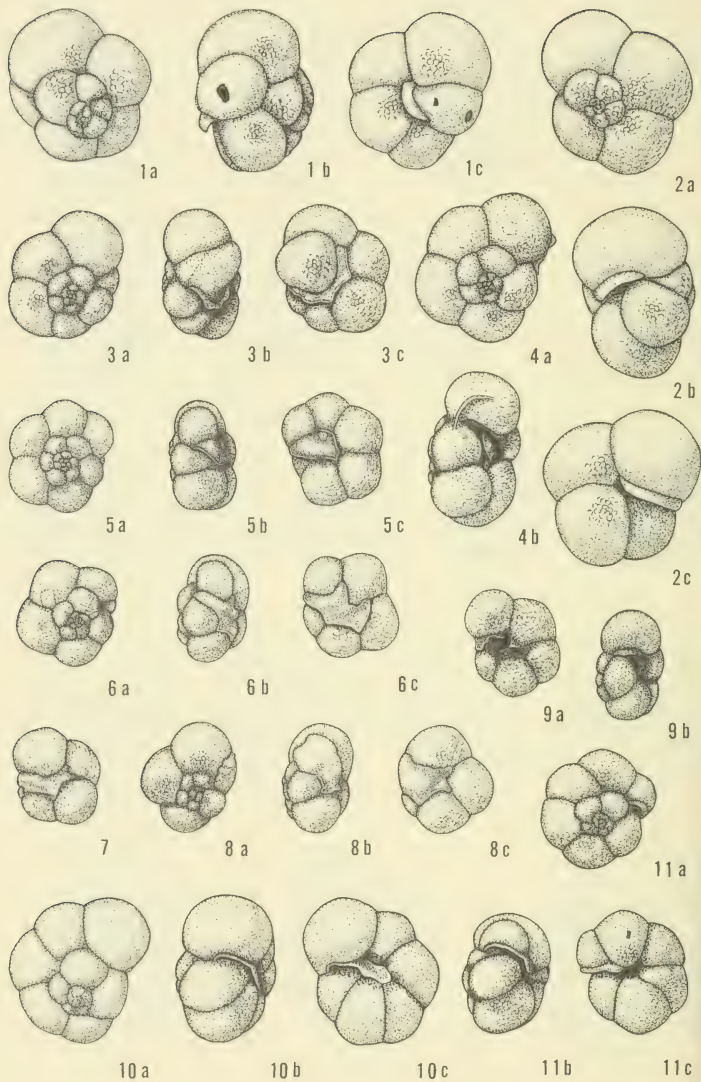
Figure	Page
1-4. Globigerinoides ruber (d'Orbigny)	156
Figs. 1b, 2b, 3b, 4b, side views; all others, edge views; X52. Fig. 1, early form (like modern high-latitude form of Parker, 1962); fig. 2, later form (like modern "group 2" form of Parker, 1962); fig. 3, typical form (like modern warm-water form of Parker, 1962); fig. 4, variant form (included in "group 2" by Parker, 1962). Figs. 1, 2, CAP 38 BP: fig. 1, 456-458 cm, fig. 2, 249-250 cm; figs. 3, 4, DODO 117 P, 16-18 cm. USNM Nos. 643019-643022.	
5. Globigerinella siphonifera (d'Orbigny)	152
Fig. 5a, side view; fig. 5b, edge view; X52. LSDH 78 P, 30-32 cm. USNM 643023.	
6. Hastigerina pelagica (d'Orbigny)	159
Fig. 6a, side view; fig. 6b, edge view; X52. CAP 38 BP, 860-862 cm. USNM No. 643024.	
7, 8. Orbulina spp.	159
Side views; X36. Fig. 7, Miocene bilobate form; fig. 8, modern bilobate form. Fig. 7, CAP 38 BP, 674-676 cm; fig. 8, DWBG 83, 0-3 cm (Recent; lat. 44°03.5'S., long. 95°42'W.; 4660 m). USNM Nos. 643025, 643026.	

EXPLANATION OF PLATE 23

All figures Xca.40

Figure	Page
1-5. Sphaeroidinella seminulina (Schwager)	161
Fig. 4b, edge view; all others, side views. Figs. 1, 2, 4, 5, LSDH 78 P; figs. 1, 4, 74-77 cm, fig. 2, 499-502 cm, fig. 5, 100-102 cm; fig. 3, CAP 38 BP, 579-582 cm. USNM Nos. 643027-643031.	
6, 7. Sphaeroidinella subdehiscens Blow	162
Figs. 6b, 7b, edge views; all others, side views. LSDH 78 P; fig. 6, 100-102 cm; fig. 7, 74-77 cm. USNM Nos. 643032, 643033.	
8, 9. Sphaeroidinella dehiscens (Parker and Jones)	160
Side views. Fig. 8, primitive specimen; fig. 9, typical specimen. LSDH 78 P; fig. 8, 450-453 cm; fig. 9, 74-77 cm. USNM Nos. 643034, 643035.	





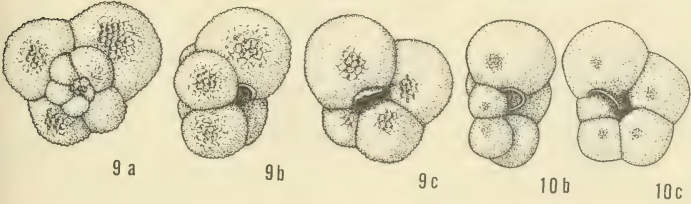
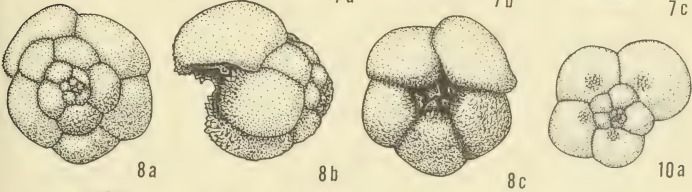
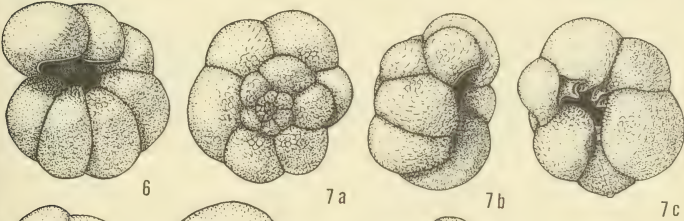
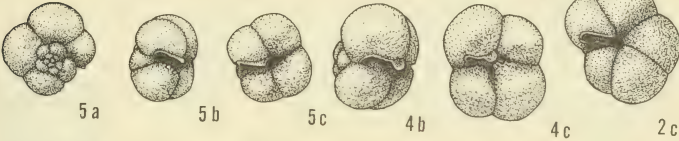
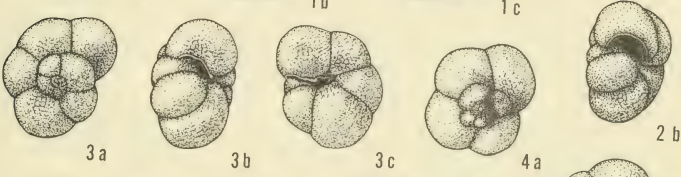
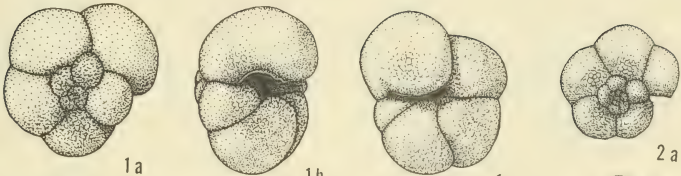
EXPLANATION OF PLATE 24

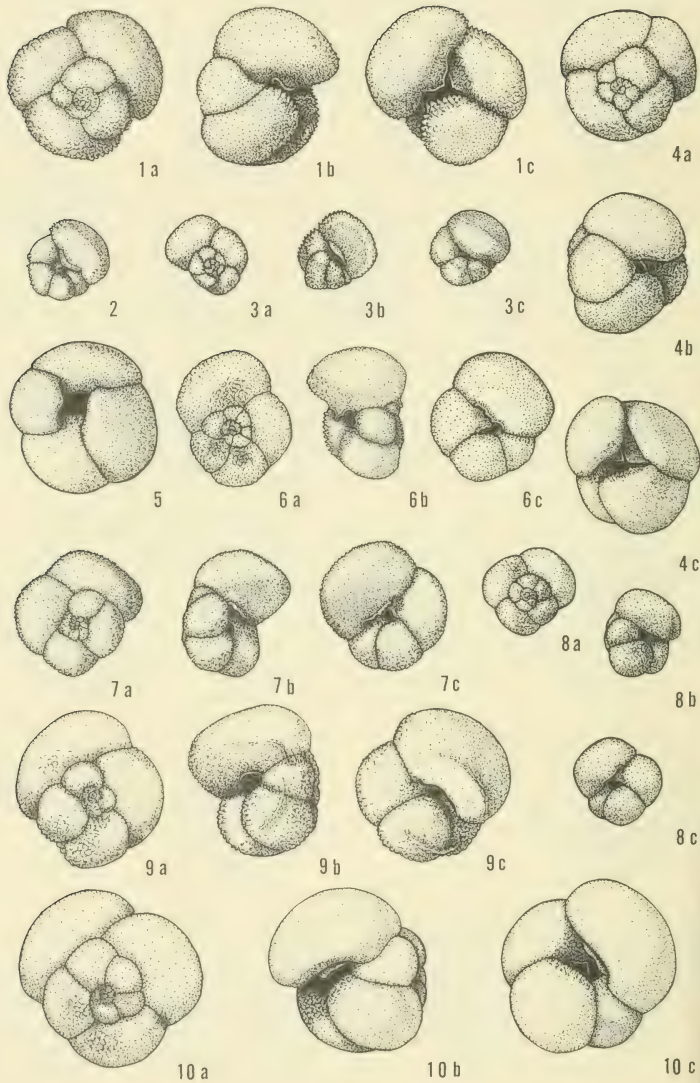
Figure	Page
1, 2. Globoquadrina continua (Blow)	166
Figs. 1b, 2b, edge views; all others, side views; X93. PROA 88 P, 449-451 cm. USNM Nos. 643036, 643037.	
3-9. Globoquadrina acostaensis (Blow)	164
Figs. 3b, 4b, 5b, 6b, 8b, 9b, edge views; all others, side views; X52. Figs. 4, 9, specimens with the apertural tooth of the final chamber broken away. CAP 38 BP, 860-862 cm. USNM Nos. 643038-643044.	
10, 11. Globoquadrina humerosa (Takayanagi and Saito)	169
Figs. 10b, 11b, edge views; all others, side views; X52. LSDH 78 P, 150-153 cm. USNM Nos. 643045, 643046.	

EXPLANATION OF PLATE 25

All figures X 52

Figure	Page
1-6. Globoquadrina humerosa (Takayanagi and Saito)	169
Figs. 1b, 2b, 3b, 4b, 5b, edge views; all others, side views. Figs. 1-5, LSDH 78 P, 150-153 cm; fig. 6, CAP 38 BP, 426-428 cm. USNM Nos. 643047-643052.	
7. Globoquadrina dutertrei (d'Orbigny)	168
Figs. 7a, c, side views; fig. 7b, edge view. ZEPH I 13, 52-57 cm (Quaternary; lat. 20°08'N., long. 49°01'W.; 4632 m). USNM No. 643053.	
8. Globoquadrina altispira (Cushman and Jarvis)	165
Figs. 8a, c, side views; fig. 8b, edge view. LSDH 78 P, 74-77 cm. USNM No. 643054.	
9, 10. Globoquadrina hexagona (Natland)	169
Figs. 9b, 10b, edge views; all others, side views. CAP 38 BP; fig. 9, 631-633 cm; fig. 10, 528-530 cm. USNM Nos. 643055, 643056.	



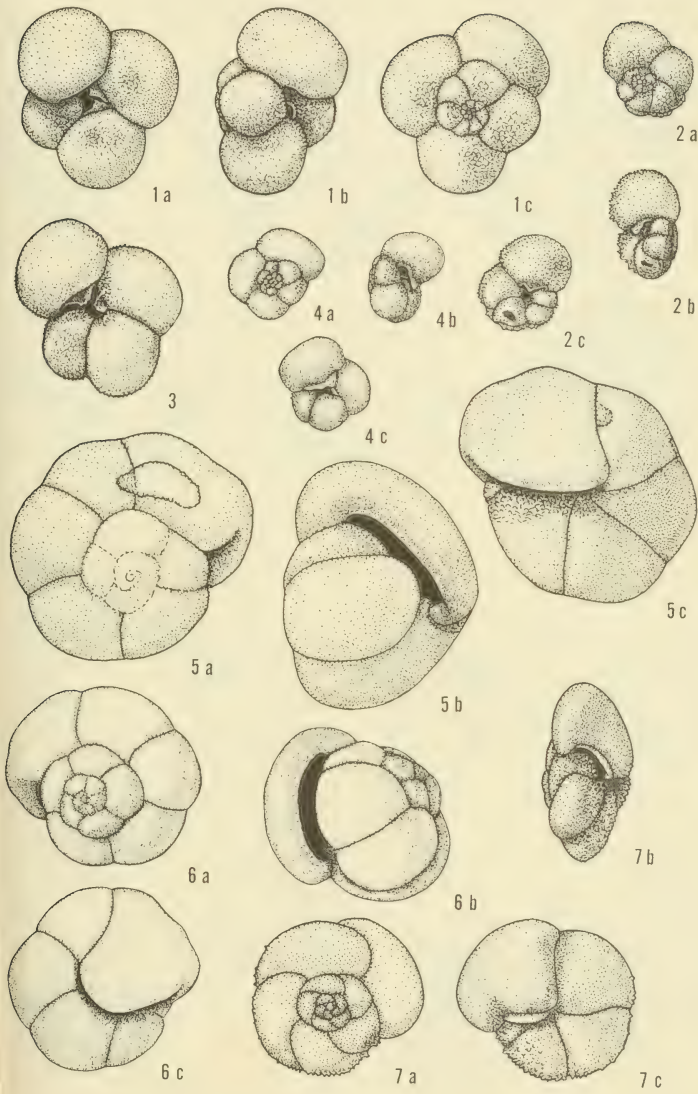


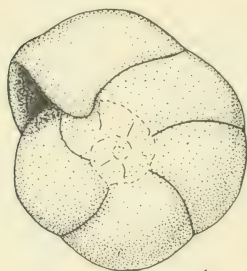
EXPLANATION OF PLATE 26

Figure	Page
1-3. Globoquadrina dehiscens (Chapman, Parr, and Collins)	166
Figs. 1b, 3b, edge views; all others, side views (fig. 2 is tipped to show the apertural face more clearly); X36. CAP 38 BP, 860-862 cm. USNM Nos. 643057-643059.	
4-10. Globoquadrina venezuelana (Hedberg)	171
Figs. 4b, 6b, 7b, 8b, 9b, 10b, edge views; all others, side views; X36. Figs. 6, 7, 9, pre-adult stages; fig. 8, earlier stage; fig. 10, adult specimen transitional to <i>G. conglomerata</i> . Figs. 4, 5, 8, CAP 38 BP; figs. 4, 5, 860-862 cm, fig. 8, 528-530 cm; figs. 6, 7, 9, 10, LSDH 78 P: fig. 6, 100-102 cm, figs. 7, 9, 10, 74-77 cm. USNM Nos. 643060-643066.	

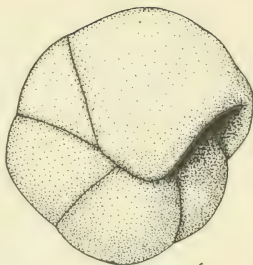
EXPLANATION OF PLATE 27

Figure	Page
1-3. Globoquadrina pseudofoliata , n. sp.	170
Figs. 1b, 2b, edge views; all others, side views; X36. LSDH 78 P, 30-32 cm. Fig. 1, holotype, USNM No. 643067; figs. 2, 3, paratypes (fig. 2, early stage, dissected from an adult), USNM Nos. 643068, 643069.	
4. Globoquadrina conglomerata (Schwager)	165
Figs. 4a, c, side views; fig. 4b, edge view; X36. Early stage. CAP 38 BP, 0-10 cm. USNM No. 643070.	
5, 6. Pulleniatina primalis Banner and Blow	173
Figs. 5b, 6b, edge views; all others, side views; X ca.72. Fig. 5, transitional to <i>P. obliquiloculata</i> . CAP 38 BP; fig. 5, 579-582 cm; fig. 6, 860-862 cm. USNM Nos. 643071, 643072.	
7. Globorotalia scitula (Brady)	181
Figs. 7a, c, side views; fig. 7b, edge view; X39. LSDH 78 P, 30-32 cm. USNM No. 643073.	

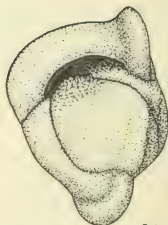




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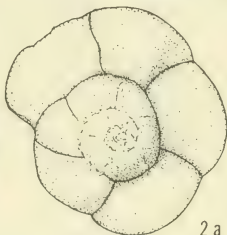
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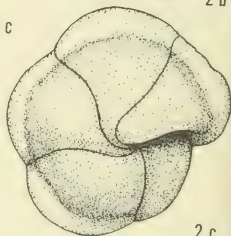
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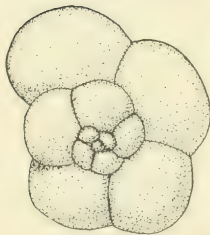
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2c



3a



3b



3c



6



7



4a



4b



5



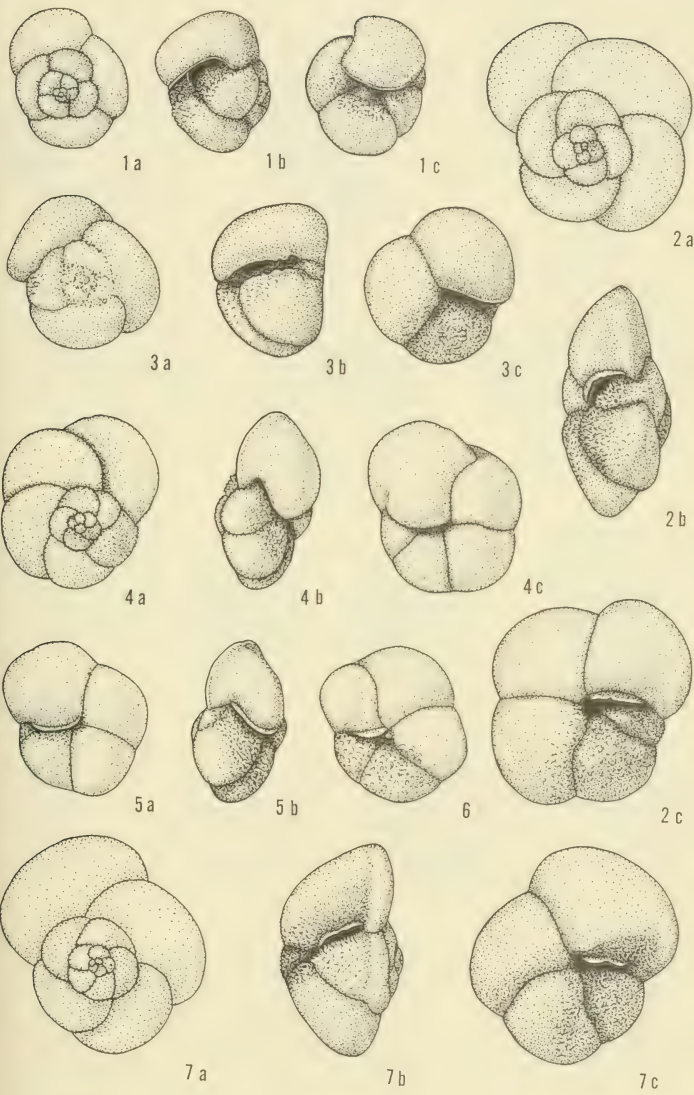
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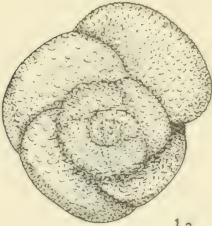
EXPLANATION OF PLATE 28

Figure	Page
1. Pulleniatina obliquiloculata (Parker and Jones) ...	172
Figs. 1a, c, side views; fig. 1b, edge view; X72. CAP 38 BP, 249-250 cm. USNM 643074.	
2. Pulleniatina spectabilis Parker	174
Figs. 2a, c, side views; fig. 2b, edge view; X52. CAP 38 BP, 528-530 cm. USNM 643075.	
3-8. Globorotalia anfracta , n. sp.	175
Figs. 3b, 4b, 6, edge views; all others, side views; X156. Fig. 3, holotype, USNM No. 643076; figs. 4-8, paratypes, USNM Nos. 643077-643081. Figs. 3-5, CHUB IV G, 0-3 cm; figs. 6-8, VS 58 (Gulf of California, lat. 24°08.3'N., long. 109°15.1'W.; 17 cm net haul, 0-50 m).	

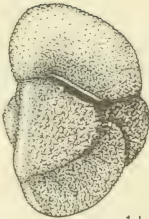
EXPLANATION OF PLATE 29

Figure	Page
1, 3. Globorotalia inflata (d'Orbigny)	179
Figs. 1b, 3b, edge views; all others, side views; X39. Fig. 1, typical form; fig. 3, variant form. Fig. 1, DODO 57 P, 20-22 cm; fig. 3, DODO 117 P, 164-166 cm. USNM Nos. 643082, 643083.	
2, 7. Globorotalia crassula Cushman and R. E. Stewart	177
Figs. 2b, 7b, edge views; all others, side views; X52. CAP 38 BP, 145-150 cm. USNM Nos. 643084, 643085.	
4-6. Globorotalia cibaoensis Bermúdez	175
Figs. 4b, 5b, edge views; all others, side views; X52. CAP 38 BP, 860-862 cm. USNM Nos. 643086-643088.	

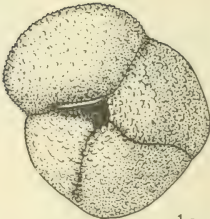




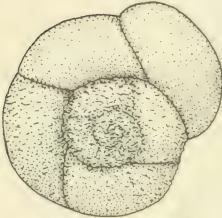
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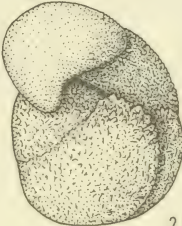
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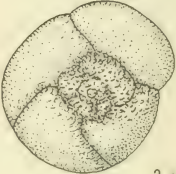
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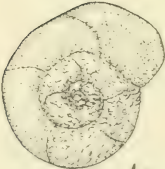
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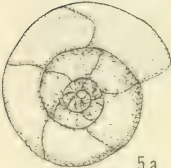
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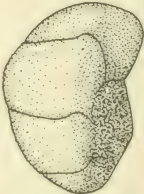
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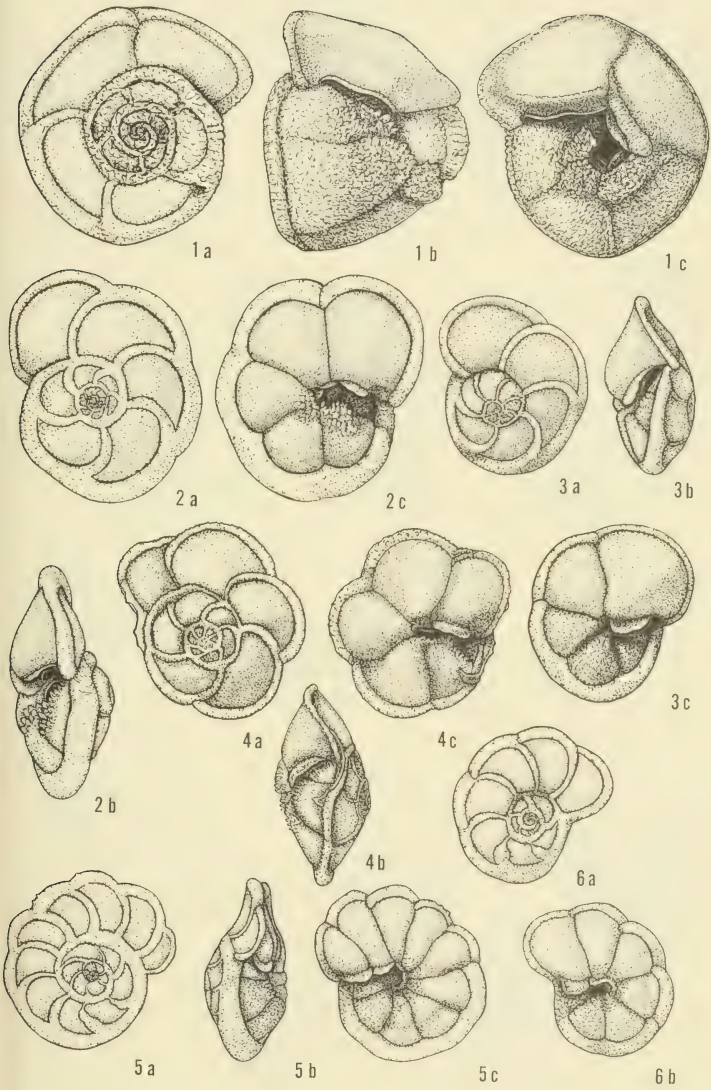
EXPLANATION OF PLATE 30

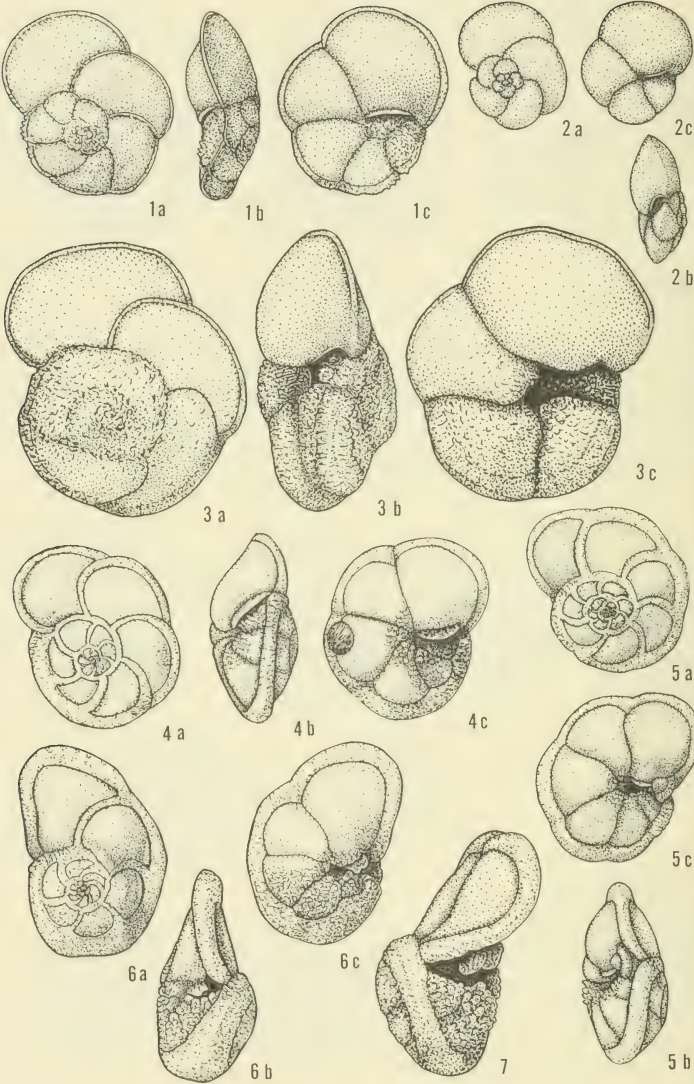
All figures X 52

Figure	Page
1-3. Globorotalia crassaformis (Galloway and Wissler)	176
Figs. 1b, 2b, 3b, edge views; all others, side views. Figs. 1, 3, MSN 56 P, 79-81 cm; fig. 2, DODO 117 P, 230-232 cm. USNM Nos. 643089-643091.	
4-7. Globorotalia tosaensis Takayanagi and Saito	181
Figs. 4b, 5b, 6b, 7, edge views; all others, side views. Figs. 4, 5, 6, CAP 38 BP: fig. 4, 408-410 cm, figs. 5, 6, 426-428 cm; fig. 7, LSDA SCS 5G, 159-161 cm. USNM Nos. 643092-643095.	

EXPLANATION OF PLATE 31

Figure	Page
1. Globorotalia truncatulinoides (d'Orbigny)	181
Figs. 1a, c, side views; fig. 1b, edge view; X52. CAP 38 BP, 145-150 cm. USNM No. 643096.	
2, 3. Globorotalia cultrata (d'Orbigny)	177
Figs. 2b, 3b, edge views; all others, side views; X34. CAP 38 BP, 426-428 cm. USNM Nos. 643097, 643098.	
4. Globorotalia fimbriata (Brady)	178
Figs. 4a, c, side views; fig. 4b, edge view; X34. CAP 38 BP, 426-428 cm. USNM No. 643099.	
5, 6. Globorotalia multicamerata Cushman and Jarvis	180
Fig. 5b, edge view; all others, side views; X34. LSDH 78 P, 299-302 cm. USNM Nos. 643100, 643101.	





EXPLANATION OF PLATE 32

Figure	Page
1, 2. Globorotalia margaritae Bolli and Bermúdez	179
Figs. 1b, 2b, edge views; all others, side views; X52. LSDH 78 P; fig. 1, 100-102 cm; fig. 2, 450-453 cm. USNM Nos. 643102, 643103.	
3. Globorotalia hirsuta (d'Orbigny)	178
Figs. 3a, c, side views; fig. 3b, edge view; X52. DODO 117 P, 164-166 cm. USNM No. 643104.	
4. Globorotalia merotumida Banner and Blow	180
Figs. 4a, c, side views; fig. 4b, edge view; X64. PROA 88 P, 278- 280 cm. USNM No. 643105.	
5-7. Globorotalia tumida (Brady)	182
Figs. 5b, 6b, 7, edge views; all others, side views; X34. Fig. 5, primitive form; fig. 6, typical form; fig. 7, flexuose form. CAP 38 BP; fig. 5, 739-741 cm; figs. 6, 7, 579-582 cm. USNM Nos. 643106-643108.	

INDEX

Note: Light face figures refer to the page number. Bold face figures refer to the plate number.

A			conglobatus,		
acostaensis,			Globigerinoides	20	137, 154, 158
Globoquadrina	24	128, 136, 137, 143, 144, 163-166, 169, 170, 172	conglomerata,		
			Globigerina		120
adamsi, Globigerinella	..	140, 152	Globoquadrina	27	139, 140, 165, 170, 171
advena, Globoquadrina			continua,		
quadriaria		167	Globoquadrina	24	136, 163, 166
aequilateralis,			crassa, Pulvinulina		176, 177
Globigerina		152, 153	crassaformis,		
altispira,			Globorotalia	30	120, 128, 137, 139, 142, 176, 177, 181
Globoquadrina	25	119, 120, 122, 123, 125, 138, 140, 155, 157, 165, 168	crassula, Globorotalia	29	137, 177, 178
			cristata, Globigerina	....	147
Globoquadrina			Cubagua well 1,		
altispira	...	120, 123	Venezuela	.....	122
Altonian, New Zealand..		161	cultrata,		
ambitacrena,			Globorotalia	31	120, 137, 177, 178, 180
Tinophodella	..	146	D		
anfracta,			decoraperta,		
Globorotalia	28	139, 175	Globigerina	19	125, 139, 149, 152
antillensis, Globigerina..		172, 173	dehiscens,		
cf. apertura, Globigerina		171	Globoquadrina	26	137, 157, 163, 166, 171
B			Sphaeroidinella	23	117, 120, 125, 128, 136, 137, 143, 151, 153, 159-162
Bairnsdalian, Australia	..	166	Sphaeroidinella		
balthica, Hyaline	..	117	dehiscens	.....	120
Beela	.....	149	digitata, Globigerina	19	140, 150, 152
Belgium	.....	169	cf. digitata, Globigerina		150
bilobata, Globigerina	....	160	disjuncta,		
Blake Plateau	.....	123, 176	Sphaeroidinella	.....	161
Bodjonegoro-1 well,			dissimilis, Globigerina	..	142, 162
Java	.....	124, 155	Donni Sandstone Member,		
bollii,			Saipan	.....	124, 125
Globigerinoides	20	123, 139, 153	dutertrei,		
Borneo	.....	124	Globoquadrina	25	116, 123, 125, 128, 139, 140, 143, 144, 164, 168, 170
bradyi, Globigerina	..	146	E		
bulloides, Globigerina	..	125	eggeri, Globigerina	.....	168
C			elongatus,		
Calabrian, Italy	.....	117	Globigerinoides	.....	156
calida, Globigerina	18	137, 139, 149	Eniwetok		124
cf. canariensis,			eobulloides, Globigerina		
Globorotalia	.....	122	(Eoglobigerina)	.....	145
Candeina	.....	145			
Catapsydrax		142, 162, 164			
centralis, Globorotalia	..	142			
cibaensis,					
Globorotalia	29	137, 175, 177			

INDEX

Eocene	123	Guam	124
Eoglobigerina	145	Gulf of Alaska	164
Experimental Mohole ..	125	Gulf of California	158, 175
extremus, Globigerinoides		Gulf of Mexico	123
obliquus	123, 155		
F			
falconensis,		Hastigerina	159
Globigerina .. 19	125, 138, 140,	Helvetian	125
	141, 150	hexagona,	
Fiji	115, 130, 180	Globoquadrina	25 137, 169, 170
fijiensis, Globorotalia		hirsuta, Globorotalia	32 138, 140,
cultrata	120		177-179
Globorotalia menardii	180	humerosa,	
fimbriata,		Globoquadrina 24, 25	122, 125, 128,
Globorotalia .. 31	178		137, 139, 143, 144,
finalis, Pulleniatina			157, 164, 165, 168,
obliquiloculata	172, 173		169
fistulosus,		humilis,	
Globigerinoides ....21	120, 136, 138,	Turborotalita	17 137, 145, 146
	140, 154	hystericus, Globigerinoides	
Globigerinoides		quadrilobatus	154
quadrilobatus	120, 154		
flexuosa, Pulvinulina		I	
tumida	182	immatura, Sphaeroidinella	
foliata, Globigerina ..	170	dehiscens	120, 160
G			
Gellibrand Clay,		inflata, Globorotalia ..29	116, 120, 125,
Australia	166		139-141
Globanomalina	147	involuta, Globigerina	
Globigerina	143, 149, 153,	aequilateralis	153
	163	iota, Globigerinita ....17	138, 145, 146
Globigerinella	152		
Globigerinita	146	J	
Globigerinoides	142, 143, 149,	Java	124, 155
	153, 160	JOIDES hole 3	123
Globoquadrina	142, 143, 162,		
	163	K	
globorotaloidea,		kochi, Globigerina ..	161
Globigerina	169		
Globorotalia	142, 143, 147,	L	
	163, 164, 175	Le Castella, Italy	117
Globorotaloides ..	143, 162, 163	Lamont core V3-153	116, 117, 123,
globosa, Globoquadrina			136, 176
altispira	165	larmeu, Globoquadrina	166, 167
globularis, Globigerina ..	169	lenguaensis,	
glutinata,		Globorotalia	120
Globigerinita	17 138, 145, 146	limbata, Rotalia	177, 178
grimsdalei, Globigerina..	161		
groenlandica,		M	
Globigerina ..	151	margaritae,	
		Globorotalia .. 32	122, 128, 137,
			138, 140, 141,
			175, 178, 179

INDEX

menardii, Globorotalia..	180	patagonica,	
Pulvinulina ..	116	Pulvinulina ..	181
Rotalia (Rotalia)	177, 178	Peikang Shelf, Taiwan ..	124
merotumida,		pelagica, Hastigerina	22 137, 159
Globorotalia	32 136, 180	Philippines ..	119, 120, 124
Messinian, Sicily	116	plesiotumida, Globorotalia	
minuta, Globigerinoides	146	tumida	136, 180, 182
miocenica, Globorotalia	123	Pontian	119, 125
miozea, Globorotalia ..	176, 177, 179	Pozón Formation ..	122
multicamerata,		praecursor, Pulleniatina	
Globorotalia	31 119, 120, 123, 137-139, 178, 180	obliquiloculata	173
multiloba,		praedigitata,	
Sphaeroidinella	161	Globigerina	19 137, 140, 150, 151
murrayi, Hastigerina	159	praepumilio,	
		Globanomalina	18 138, 140, 147, 148
N		primalis,	
nepenthes,		Pulleniatina	27 137-139, 157, 163, 172-174
Globigerina	19 119, 120, 123-125, 138, 150, 157	pseudobulloides,	
		Globigerina ...	145, 163
New Ireland, Bismarck		pseudofoliata,	
Archipelago	157	Globoquadrina	27 138, 140, 166, 170, 171
nitida, Candeina ..	17 137, 145	Pseudohastigerina	147
Rotalia	177, 178	Pulleniatina	116, 138, 142, 143, 149, 163, 172
Nobori Formation,		pumilio, Globanomalina	
Japan ..	124, 125, 150, 169	(?)	18 140, 145, 147, 148
O		puncticulata,	
obesa, Globoquadrina ..	166, 167	Globorotalia	116, 179
Globorotalia	152	punctulata, Globorotalia	176
obliquiloculata,			
Pulleniatina	28 138, 172-174	Q	
Pulleniatina		quadraria,	
obliquiloculata	138, 172	Globoquadrina	166, 167
obliquus,		Globorotalia	166
Globigerinoides	20 123, 125, 139, 154, 155, 157	quadrilobatus,	
		Globigerina	157
oceanica, Globorotalia		Globigerinoides	120, 143, 153, 154, 156
(Turborotalia)	176	quinqueloba,	
Oligocene	147, 169	Globigerina	125
operta, Eoglobigerina	145	cf. quinqueloba,	
Orbulina	137, 159	Globigerina	18 137, 151
ovalis, Globanomalina ..	147, 148		
P		R	
pachyderma,		rotundata, Globigerina ..	168
Globigerina	125	ruber,	
parkeri, Globigerinita ..	147	Globigerinoides	22 123, 137, 138, 156, 158
Globigerinoides	146		

INDEX

rubescens,
Globigerina 19 123, 124, 139,
140, 149, 152
rutschi, Sphaeroidinella 161, 162

S

sacculifer, Globigerina .. 116, 156
Globigerinoides21 137, 139, 143,
153, 154, 156,
160, 182
Saipan 124
Santa Maria di
Catanzaro, Italy 117
Sarmatian 120, 125
scitula,
Globorotalia27 137, 175, 176,
181
semiinvoluta,
Pulleniatina 173
seminulina,
Sphaeroidinella23 116, 125, 139,
150, 157, 160-162
siakensis, Globorotalia .. 120
siphonifera, Globigerina .. 152
Globigerinella22 140, 152
Solomon Islands 120
Sômachî Formation,
Japan 124
sp., Globigerina 146, 161, 171
Globigerinella 152
Orbulina
(bilobate) 22 137, 159
sp. 1, Globorotalia 179
spectabilis,
Pulleniatina28 138, 139, 172,
174
Sphaeroidinella 126, 143, 153,
160
Sphaeroidinellopsis .. 153, 160
spinulosa,
Sphaeroidinella 162
Subbotina 142, 162, 163
subcretacea, Globigerina .. 168
Globoquadrina
dutertei 144
subdehiscens,
Globoquadrina 166
Sphaeroidinella23 116, 128, 136,
137, 153, 157,
160-162
SUBMAREX 6301 123
Sumatra 124
suturi, Globoquadrina .. 169

Suva Formation,
Viti Levu, Fiji 130, 137

T

Tabianian, Italy 116, 179
Tagpochau Formation,
Saipan 124
Tanganyika 169
tenellus,
Globigerinoides 123, 140, 159
Tortonian, Italy 124, 144
tosaensis,
Globorotalia30 117, 119, 120,
123, 124, 128, 138-140,
142, 177, 181, 182
trilobus,
Globigerinoides 143, 153, 157
triloculinoides,
Subbotina 142, 163
trochospira, Pulleniatina
obliquiloculata 172
"Trubi" beds, Sicily 116
truncatulinoides,
Globorotalia31 117, 119, 120,
123, 128, 136,
139-142, 177, 181
tumida, Globorotalia 32 120, 136, 137,
142, 157, 175, 178,
180, 182
Pulvinulina
menardii 116
Turborotalia 142, 143, 163,
175
Turborotalita 145, 146, 174

U

universa, Orbulina 159
uvula, Globigerinita 17 146

V

variabilis,
Globorotaloides 142, 163
venezuelana,
Globoquadrina26 138, 139, 157,
165-168, 170, 171
Vindebonian, Spain 169

Z

Zanclean, Sicily 116

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MIOCENE-PLIOCENE BOUNDARY IN
SOUTHERN CALIFORNIA**

By

JAMES C. INGLE, JR.

1967

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CONTENTS

	Page
Abstract	217
Acknowledgments	218
Introduction	218
Purpose and scope	218
Philosophy of the problem	220
Location and geologic setting	224
Field and laboratory procedures	233
Previous work	237
General	237
Use of benthic foraminiferal stages	237
Time transgressive nature of benthic assemblages	238
Paleobathymetric and paleoecologic interpretations	241
General	241
Gross population trends	242
Foraminiferal number	242
Planktonic-benthic ratio	242
Species diversity	243
Radiolarian trends	243
Benthic faunal groups	244
Displaced species	247
Malaga Cove section	250
General stratigraphy	250
Lithofacies and biofacies trends	253
Radiolaria-diatom facies	253
Radiolarian facies	256
Glauconitic-foraminiferal facies	257
Summary	259
Repetto Hills section	260
General stratigraphy	260
Biofacies trends	263
Comparison with the Bunker Hill section	264
Summary	265
Woodland Hills and Mission Hills sections	266

General stratigraphy	266
Lithofacies and biofacies trends	268
Tarzana Submarine Fan facies	268
Diatom-Radiolaria facies	271
Basin slope facies	273
Shelf facies	274
Summary	275
Planktonic facies variation	276
General	276
Effect of an asymmetric current system	278
Effect of the California Current on Miocene to Recent planktonic assemblages	281
Planktonic facies variation with depth	286
Late Miocene and Pliocene planktonic zonation in southern California	289
Late Miocene trends	289
Range of <i>Prunopyle titan</i>	295
Early Pliocene trends	297
Middle Pliocene trends	302
Late Pliocene trends	303
Pleistocene trends	307
Summary of late Tertiary planktonic trends	309
Paleo-oceanographic inferences	313
Planktonic correlation of epicontinental deposits	316
Correlation of epicontinental and adjacent deep-sea sediments	320
Upper Tertiary planktonic biofacies variation along the marginal eastern North Pacific	325
Comparison of upper Tertiary planktonic biofacies in the western and eastern marginal North Pacific	331
Summary and conclusions	335
References	342
Faunal reference list	356
Foraminifera	356
Planktonic species	356
Benthic species	357
Radiolaria	365
Appendix	366
Plates	373
Index	385

LIST OF TEXT-FIGURES

1. Location map of southern California showing position of upper Tertiary sections utilized during investigation of Miocene and Pliocene microfaunal facies	221
2. Location map showing the geographic relationship between filled Tertiary marine basins on the southern California mainland and existing marine basins within the continental borderland offshore	222
3. Correlation chart illustrating the commonly recognized relationships between middle Miocene through Pleistocene microfaunal stages and corresponding lithologic units utilized in the Ventura, Los Angeles, and Capistrano-San Diego areas	223
4. Sample location map of the Repetto Hills section, Los Angeles County, California	226
5. Location map of the Bunker Hill section, Los Angeles County, California	227
6. Location map of the Malaga Cove section, Los Angeles County, California	228
7. Location of sample traverses within the section of Miocene and Pliocene strata exposed in the sea cliff at Malaga Cove	229
8. Sample location map, Woodland Hills section, Los Angeles County, California	230
9. Sample location map, Mission Hills section, Los Angeles County, California	231
10. Sample location map, Balcom Canyon section, Ventura County, California	232
11. Location map of spot samples collected from the San Diego Formation exposed in sea cliff at Pacific Beach, San Diego County, California	233
12. Location of Recent sediment samples utilized and position of pertinent upper Tertiary sections mentioned in text	234
13. Bathymetric distribution of selected modern benthic Foraminifera	235
14. Planktonic correlation of bathyal upper Tertiary sequences within the Capistrano Embayment, Orange County, California (after Ingle 1962, 1963a)	240
15. Distribution of benthic Foraminifera within a turbidite sequence in the Pliocene Pico Formation, Balcom Canyon	248
16. Cumulative percentage of benthic faunal groups and absolute ranges of selected benthic species within the Malaga Cove section	251
17. Foraminiferal number, radiolarian number, glauconite abundance, and estimated paleobathymetry within the Malaga Cove section	252
18. Cumulative percentage of benthic faunal groups and absolute ranges of selected benthic species within the Repetto Hills section	261
19. Foraminiferal number, percentage of planktonic and benthic species, number of benthic species percentage of displaced specimens, and estimated paleobathymetry of the Repetto Hills section	262
20. Cumulative percentage of benthic faunal groups and absolute ranges of significant benthic species within the Woodland Hills section	267

21. Foraminiferal number, number of benthic species, percentage of planktonic and benthic species, radiolarian number, percentage of displaced Foraminifera, and estimated paleobathymetry within the Woodland Hills section	269
22. Benthic and planktonic faunal trends within the Mission Hills section	272
23. Generalized surface temperature and surface circulation in the North Pacific	279
24. Distribution of selected common planktonic Foraminifera in the marginal eastern and western North Pacific	280
25. Cumulative distribution of planktonic Foraminifera along a north-south traverse in the marginal eastern North Pacific	281
26. Cumulative frequency of common planktonic Foraminifera in the inlet portal section of the Tecolote Tunnel	283
27. Cumulative frequency of common planktonic Foraminifera, coiling ratio of <i>Globigerina pachyderma</i> , stratigraphic ranges of important minor species, and absolute range of <i>Prunopyle titan</i> in the Newport Mesa section	285
28. Cumulative frequency of planktonic Foraminifera within a series of progressively deeper samples off southern California	287
29. Planktonic foraminiferal trends and paleobathymetric trends within a portion of the Pliocene Pico Formation exposed in Balcom Canyon	288
30. Cumulative frequency of common planktonic species, coiling ratio of <i>Globigerina pachyderma</i> , absolute ranges of selected planktonic species, and absolute range of <i>Prunopyle titan</i> within the Woodland Hills section	290
31. Cumulative frequency of common planktonic species, coiling ratio of <i>Globigerina pachyderma</i> , absolute ranges of selected planktonic species, and absolute range of <i>Prunopyle titan</i> within the Malaga Cove section	296
32. Cumulative frequency of common planktonic species, coiling ratio of <i>Globigerina pachyderma</i> , and absolute ranges of selected planktonic species within the Repetto Hills section	300
33. Cumulative frequency of common planktonic species, coiling ratio of <i>Globigerina pachyderma</i> , and absolute ranges of selected planktonic and benthic species within the Bunker Hills section	308
34. Summary range chart of planktonic Foraminifera in the late Tertiary of southern California	310
35. Planktonic foraminiferal zonation of the late Tertiary in southern California and suggested correlation with the "standard" tropical planktonic zonation	314
36. Variation in sea surface temperature during the late Tertiary at latitude 33° in the marginal eastern North Pacific	315
37. Planktonic correlation of principal sections utilized in the Ventura, Los Angeles, and San Diego areas	317
38. Stratigraphic ranges of selected planktonic species within the experimental MOHOLE cores as plotted from data of Parker (1964)	321

39. Correlation of the lower Pliocene subtropical planktonic biofacies within the Repetto Hills section, Malaga Cove section, and the experimental MOHOLE cores	323
40. Ranges and coiling characteristics of planktonic Foraminifera from the upper Miocene Montesano Formation and the Pliocene Quinault Formation of Washington as plotted from data of Fowler (1965)	327
41. Generalized diagram illustrating poleward and equatorward regressions and transgressions of tropical, temperate, and subarctic planktonic biofacies along the marginal eastern North Pacific during the late Tertiary	330
42. Comparison of latitudinal distribution of selected planktonic Foraminifera in the marginal eastern and marginal western North Pacific during the Recent and early Pliocene	332
43. Comparison of vertical ranges of selected planktonic Foraminifera in the upper Miocene through Pleistocene of central Honshu, Japan and southern California	334

TABLES

1. Dominant benthic faunal groups	245
2. Relative abundances of Foraminifera and other microfossils within a turbidite sequence in the Pliocene Pico Formation, Balcom Canyon	283
3. Percentages of diatoms, Foraminifera, Radiolaria, and terrigenous material in selected Gulf of California basins	255
4. Relative abundances of planktonic Foraminifera from the San Diego Formation, Pacific Beach, California	304
5. Comparison of rates of sedimentation in Recent and early Pliocene sedimentary environments	325
6. Relative abundance of planktonic Foraminifera in Recent sediments of the marginal eastern North Pacific	367
7. Relative abundances of Foraminifera in the Malaga Mudstone, U.S.G.S. Locality 24, San Pedro, California	368
8. Relative abundances of Foraminifera and Radiolaria in the Repetto Formation, Malaga Mudstone, and Valmonte Diatomite exposed in the Malaga Cove section, Los Angeles County, California	In pocket
9. Relative abundances of planktonic Foraminifera in the Repetto Formation, Bunker Hill section, Los Angeles County, California	369
10. Relative abundances of Foraminifera and Radiolaria in the Repetto Formation, Repetto Hills section, Los Angeles County, California	In pocket
11. Relative abundances of Foraminifera and Radiolaria in the Repetto and Modelo Formations, Woodland Hills section, Los Angeles County, California	In pocket
12. Relative abundances of Foraminifera and Radiolaria in the Repetto and Modelo Formations, Mission Hills section, Los Angeles County California	Fold in between 369-370
13. Relative abundances of planktonic Foraminifera, Pico Formation, Balcom Canyon section, Ventura County, California	370
14. Location of Allan Hancock Foundation samples	371

FORAMINIFERAL BIOFACIES VARIATION AND THE MIOCENE-PLIOCENE BOUNDARY IN SOUTHERN CALIFORNIA¹

JAMES C. INGLE, JR.²

ABSTRACT

A quantitative analysis was made of microfaunas from bathyal upper Miocene through Pliocene sediments within the Ventura and Los Angeles basins of southern California in order to demonstrate variation of biofacies and lithofacies across the Miocene-Pliocene boundary. Planktonic and benthic biofacies are placed against a framework of available radiometric dates with the Miocene-Pliocene boundary defined as an isochronous surface at 10×10^5 years B.P.

Analogy between the distribution of Recent and fossil Foraminifera and sediments were utilized to interpret contemporary paleoecologic settings. Paleoenvironments defined within the upper Miocene and Pliocene sequences include submarine fans, steep basin slopes, oxygen-deficient basin plains, foraminiferan-barren radiolarian-rich basin deposits, flank of a seamount or bank and shelf depth deposits. A paleobathymetric curve is constructed for each section with inferred depths ranging from 3,000 to 150 meters. Synchronous planktonic horizons allow correlation of dissimilar but contemporaneous sedimentary events and benthic biofacies within the various basinal areas. These correlations also illustrate that the benthic foraminiferal stages traditionally utilized to subdivide Miocene and Pliocene strata are inherently time-transgressive.

Quantitative trends exhibited by planktonic Foraminifera are interpreted in light of the present temperature controlled distribution of planktonic species along the marginal eastern North Pacific. It is apparent that the cool, equatorward California Current has controlled the character of planktonic faunas south to latitude 25° since the middle Miocene. *Globigerina bulloides* and *G. concinna* dominate middle Miocene assemblages, whereas *G. bulloides* and *G. pachyderma* dominate late Miocene through Recent assemblages. Nevertheless, portions of the *Globorotalia mayeri*, *Sphaeroidinellopsis seminulina* and "*Sphaeroidinella dehiscentis*" zones of tropical latitudes are recognized.

Variations of temperature-sensitive planktonic biofacies indicate surface temperature has varied from 10°C to 25°C during the last 15×10^6 years off southern California. The latitudinal transgressions and regressions of subarctic, temperate, and subtropical isotherms along the marginal eastern Pacific are directly related to physical changes in the high latitude source area of the California Current. Moreover, these oscillations allow a total of nine planktonic zones to be defined in the upper Miocene through Pleistocene sequence on the basis of predominant planktonic species. The boundaries of these planktonic zones, together with the absolute limits of selected planktonic species, provide 13 useful planktonic indices. The upper limit of the radiolarian *Prunopyle titan* provides planktonic control in foraminiferan-barren lower bathyal sequences.

A subarctic planktonic biofacies marked by sinistrally coiling specimens of *Globigerina pachyderma* occurred in southern California during the late Miocene, middle Pliocene, and Pleistocene, presumably in response to periods of polar refrigeration. A major subtropical planktonic biofacies characterized by an abundance of *Globigerina eggeri* in association with *Globorotalia inflata*, *G. menardi tumida*, *Globigerinodes trilobus*, and "*Sphaeroidinella dehiscentis*" occurs in the lower Pliocene, indicating the zone of mixing between the California Current and warm equatorial water moved poleward at least 10° during this interval. A similar planktonic sequence in the MOHOLE cores allows correlation of a thick sequence of epicontinental basin sediments with a greatly telescoped section within an adjacent deep-sea abyssal plain.

Late Tertiary oscillations of subarctic, temperate, and tropical planktonic biofacies in the marginal eastern Pacific can be traced from the equator as far north as

¹ Investigation completed in May, 1966, Allan Hancock Foundation, University of Southern California.

² Currently visiting scientist, Institute of Geology and Paleontology, Tohoku University, Sendai, Japan (1966-67).

latitude 47° and demonstrate (1) the fallibility of warm temperate and subtropical planktonic indices at high latitudes, and (2) the time-transgressive nature of several planktonic indices. Comparison of late Miocene through Pleistocene planktonic sequences in southern California and Honshu, Japan, demonstrates that clockwise surface circulation in the North Pacific has continuously maintained a tropical planktonic biofacies in the marginal western Pacific, whereas at least five major latitudinal adjustments of planktonic biofacies have occurred in the marginal eastern Pacific during the same period.

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INTRODUCTION

PURPOSE AND SCOPE

Assuming that the Miocene-Pliocene boundary represents an instant or surface in time it must, by definition, transgress both lithologic and biologic facies boundaries. There is neither a ubiquitous lithology or

biota characteristic of all areas at any moment; a simple traverse from strand line to abyssal depths or from low to high latitudes corroborates this today. Southern California presents an ideal region in which to illustrate this concept. Basinal development during the late Tertiary of this region allowed a wide spectrum of marine environments to exist in close proximity at the same moment. Indeed, basin subsidence reached its climax during the late Miocene and early Pliocene with water depths attaining 3,000 meters locally. Consequently, deposition of bathyal sediments took place continuously across the Miocene-Pliocene boundary in some areas (Natland, 1948; Bandy, 1953b; Natland and Rothwell, 1954; Natland, 1957; Ingle, 1962; Yerkes, McCulloh, Schoellhamer, and Vedder, 1965). This is in contrast with common unconformities between Miocene and Pliocene sediments deposited near the strand line.

The purpose of this particular study was to examine quantitative trends in the vertical distribution of planktonic and benthic foraminiferal populations in that part of the marine sequence of southern California encompassing the Miocene-Pliocene boundary. Emphasis was placed on delineating changes in the planktonic fauna across the boundary within bathyal sequences. Resulting trends were utilized to reconstruct variations in paleo-oceanography during the late Tertiary of the region. Distinctive planktonic horizons defined were used to correlate dissimilar but contemporaneous environments within separate closed basins, on the flank of a seamount, on basin slopes, within a submarine fan, and on the adjacent deep-sea floor. Furthermore, planktonic faunas were utilized to illustrate the dominating effect of the paleo-California Current system on late Tertiary planktonic biofacies along the marginal eastern North Pacific. Discrepancies between the vertical and horizontal distribution of planktonic Foraminifera in the western and eastern marginal North Pacific during the late Tertiary were examined in light of the existing clockwise current system in the North Pacific.

Analogy between quantitative distribution of Recent and fossil benthic foraminiferal populations and sediment character were utilized to interpret various contemporary paleobathymetric and paleoecologic settings of principal sections studied. In this regard a unique problem exists in the deeper water facies; Foraminifera become rare and Radiolaria constitute the dominant faunal components, duplicating the relationship seen in middle and lower bathyal environments today (Bandy, 1953a, 1961; Bandy

and Arnal, 1957). Thus in some instances the Miocene-Pliocene boundary occurs within a foraminiferan-barren but radiolarian-rich mudstone facies.

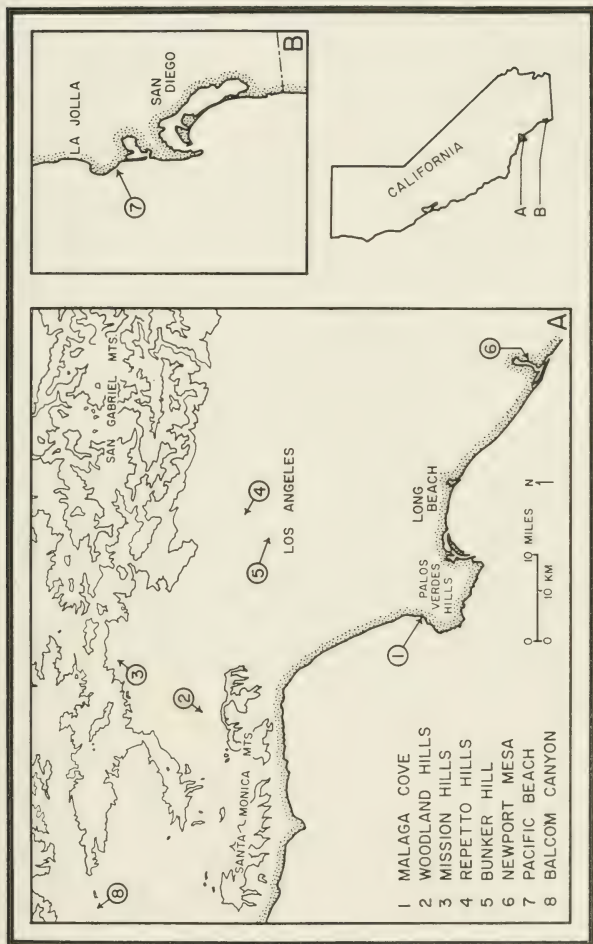
Finally, an attempt was made to place these analyses against a framework of pertinent radiometric dates (Kulp, 1961; Evernden, Curtis, Obradovich, and Kistler, 1961; Evernden, Savage, Curtis, and James, 1964; Obradovich, 1965; Yeats, 1965; Evernden *in* Bandy, 1966) and potassium-argon dates determined specifically for this investigation by Geochron Laboratories Inc. under National Science Foundation Grant GF 195.

PHILOSOPHY OF THE PROBLEM

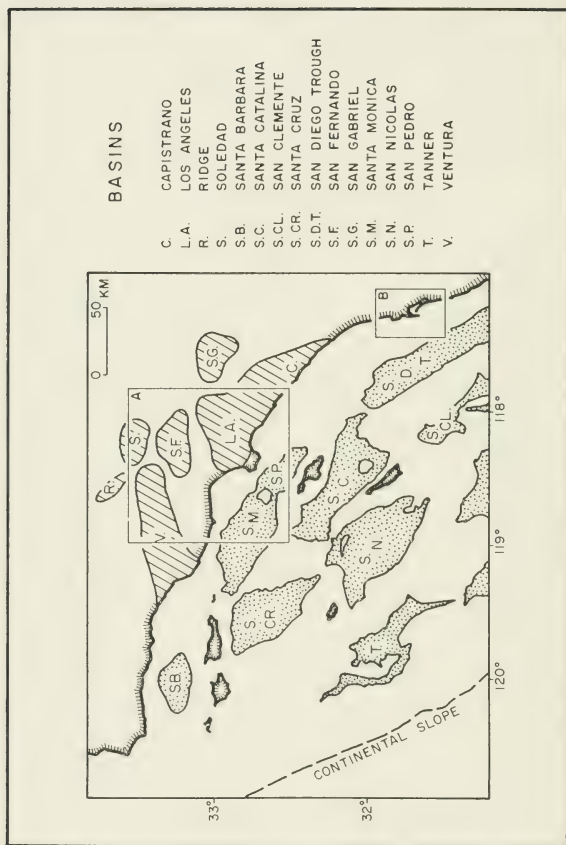
The problem of defining the Miocene-Pliocene boundary in any area is, in fact, only a small part of a much larger and fundamental problem in geology: the measurement of time. For centuries geologists have continued to substitute words for numbers primarily because of a lack of adequate instrumentation to quantitatively measure geologic and evolutionary processes. No better example of the process exists than the evolution of the geologic "time" scale (Krumbein and Sloss, 1955, p. 14). Paleontologists have been able to recognize a vertically overlapping succession of species, each limited in time, thus providing a qualitative tool with which the relative age of sediments can be recognized. However, profound arguments and varying degrees of confusion surround the majority of "boundaries" between periods, epochs, and stages thus far defined. Arguments have arisen because of the multitude of paleontologic criteria utilized to define each unit of the geologic "time" scale (*i.e.*, vertebrates, larger invertebrates, protozoans, plants) and the great horizontal distances over which the units have been extended from their type areas.

The definition of boundaries based on the vertical limits of fossils whose areal distribution was governed by their ecologic requirements does not permit easily defined time boundaries. Type sections of stages established within low latitudes seldom possess a suite of animals identical to those living at the same instant at high latitudes. Tertiary epoch and stage boundaries are especially noteworthy in this respect. This situation requires workers within high latitudes to engage in an exasperating struggle in trying to define the limits of a unit within which the arbitrarily selected "key" species were never present.

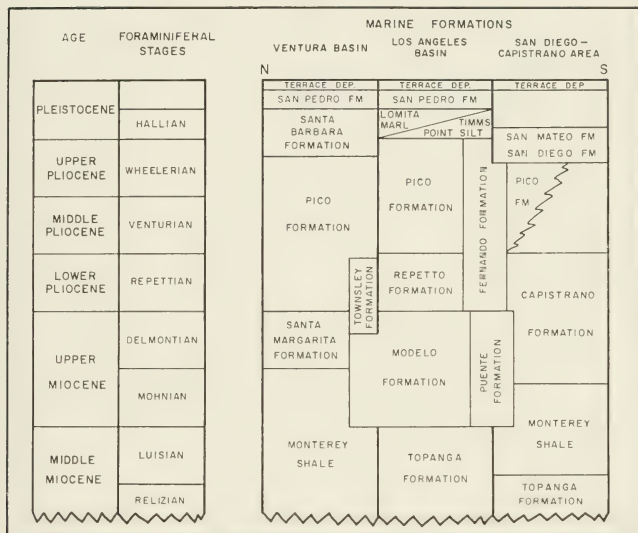
Ultimately, paleontologists and geologists have a choice to make. A stage, epoch, period, or era boundary can be defined on the basis of (1)



Text-figure 1.—Location map of southern California showing position of late Tertiary sections utilized during investigation of Miocene and Pliocene microfaunal facies.



Text figure 2.—Location map showing the geographic relationship between filled Tertiary marine basins on the southern California mainland (hatched) and existing marine basins (stippled) within the continental borderland offshore. Modified from Emery (1958; 1960, p. 51). Areas A and B covered by Text-figure 1 are outlined.



Text-figure 3.—Correlation chart illustrating the commonly recognized relationships between middle Miocene through Pleistocene microfaunal stages and corresponding lithologic units utilized in the Ventura, Los Angeles, and Capistrano-San Diego areas. Benthonic microfaunal stages after Kleinpell (1938) and Natland (1952). Formations compiled from Oakeshott, Jennings, and Turner (1954), Smith (1960), Ingle (1962), and Yerkes, McCulloh, Schoellhamer, and Vedder (1965). The Topanga, Monterey, Capistrano, and Pico Formations are absent from the San Diego area proper.

absolute time in terms of radiometric dates, (2) physical or biologic evidence of a major physical event (*i.e.*, glaciation), or (3) the appearance or disappearance of arbitrarily selected key species in time. In the light of the exponential progress of radiometric dating it seems that the most rational approach is to utilize the available radiometric scale. Some workers have already taken this step (Bandy, 1964b; Evernden, Savage, Curtis, and James, 1964). Use of a radiometric scale essentially reduces arguments over long range correlations and unit boundaries to a geochemical one regarding the reliability of dates as they appear.

A final decision remains, (1) should the arbitrarily chosen time scale be composed of equal units of time (*i.e.*, ten million year intervals) similar to a conventional ruler, or (2) should the traditional but controversial boundaries, as defined in their type areas, be retained and dated? The latter approach is currently in vogue (Holmes, 1947; Kulp, 1961; Funnel, 1964) resulting in a scale composed of unequal size units of time, a most inappropriate type of ruler where each "inch" is of different length. Nevertheless, these scales (Holmes, 1947; Kulp, 1961) represent the initial steps toward the construction of a more definitive and useful geologic time scale.

Funnel (1964) recently selected seven million years B. P. as the Miocene-Pliocene boundary, however, his data (Funnel, 1964, p. 185) and radiometric scales presented by other workers (Kulp, 1961; Evernden, Curtis, Obradovich, and Kistler, 1961; Evernden, Savage, Curtis, and James, 1964) suggest the boundary should be placed at about nine or ten million years B. P. The philosophy followed during the present investigation was simply to regard the Miocene-Pliocene boundary as an arbitrarily selected point in time ten million years before the present B. P. This date represents the maximum age of the boundary in terms of Funnel's (1964) scale. Following this concept marine rocks thought to have been deposited between fifteen to three million years B. P. in southern California were examined to determine microfossil trends across the boundary. Specific emphasis was placed on study of bathyal sediments deposited twelve to eight million years B. P.

LOCATION AND GEOLOGIC SETTING

Principal sections utilized during this study are located on the periphery of the Los Angeles and Ventura basins where Pleistocene uplift has exposed bathyal Miocene and Pliocene sediments (Text-figs. 1, 2). The basins first started to subside during the early Miocene with deepest subsidence occurring during the late Miocene and early Pliocene; both areas were filled by the late Pleistocene (Reed and Hollister, 1936, pp. 118-133, p. 140; Driver, 1948; Natland, 1957; Yerkes, McCulloh, Schoellhamer, and Vedder, 1965). Because of the wide variation in lithologic facies over relatively short distances, consistent geologic mapping has been difficult and plagued with nomenclatural difficulties as indicated in Text-figure 3. An excellent summary of stratigraphic problems in the

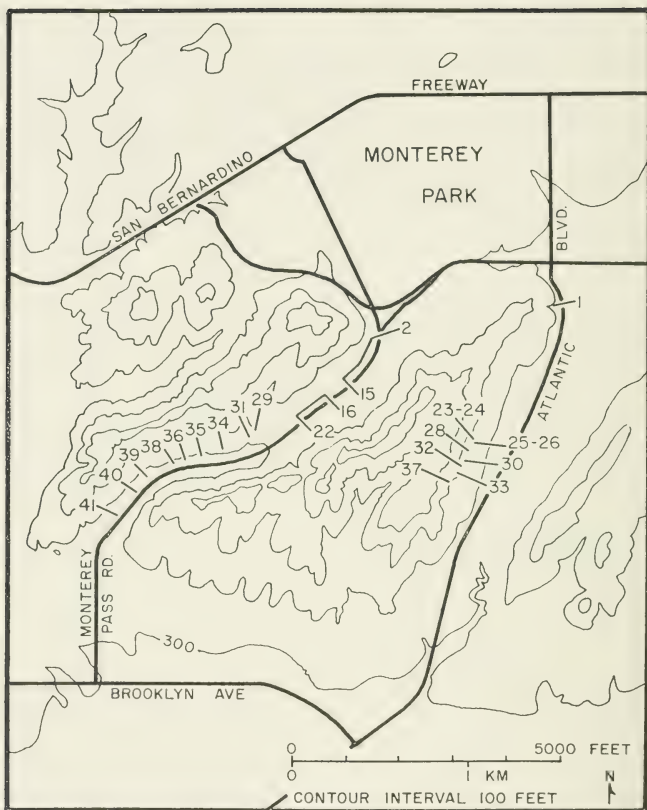
Los Angeles Basin is given by Yerkes, McCulloh, Schoellhamer, and Vedder (1965).

For the most part upper Miocene and lower Pliocene basin sediments consist of sequences of arkosic sands and silts rapidly deposited in bathyal depths by gravity mechanisms. These coarser units are interbedded with indigenous bathyal sediment types such as clayey silts, radiolarian mudstones, or diatomaceous shales (Woodford, Schoellhamer, Vedder, and Yerkes, 1954; McCulloh, Schoellhamer, and Vedder, 1965). Dominance of any specific lithology within various basins was directly related to proximity of the strand line, slope declivity, and the position of submarine canyons, and the degree of activity of submarine canyons as conduits for introduction of coarse sediments. In some cases sill depth of a basin in relation to the oxygen minimum zone controlled sediment character. The depositional history of the Los Angeles and Ventura basins is currently being duplicated in the existing basins of the Continental Borderland immediately offshore (Text-fig. 2) as discussed by Emery (1960).

Unfortunately, a continuous, foraminiferan-rich upper Miocene through lower Pliocene surface section is not available. Consequently, analysis of several sections encompassing the boundary was necessary to form a composite picture (Text-fig. 1).

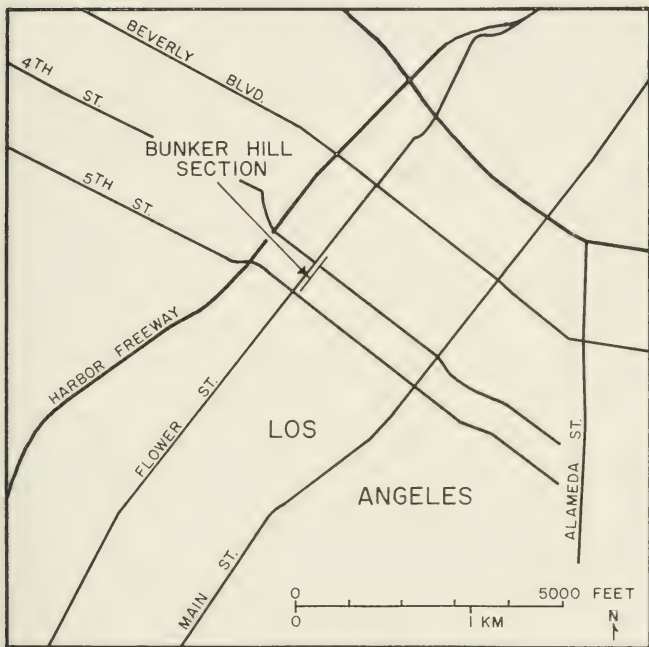
Natland (1952) designated the thick sequence of fossiliferous silts exposed in the central Repetto Hills as the type section of his lower Pliocene Repettian microfaunal stage. Prior to Natland's work, Reed (1932) selected the same section as the type area of the lower Pliocene Repetto Formation. Consequently, a quantitative analysis was made of both benthic and planktonic Foraminifera within this 1,350 meter sequence (Text-fig. 4) which for all intents and purposes represents the type Lower Pliocene of southern California. Planktonic Foraminifera were studied from an adjacent but thinner section of the Repetto Formation at Bunker Hill (Text-fig. 5) to complement Martin's (1952) earlier work on the benthic fauna.

A section of Repetto Formation exposed within a series of faulted anticlines and synclines at Malaga Cove (Text-figs. 6, 7) was utilized primarily because of the unusually prolific numbers of Foraminifera contained within it. In this section, the entire Repetto Formation is represented by less than 45 meters of glauconitic, foraminiferan-rich siltstone, a sediment type characteristic of bank tops, seamounts, and other areas



LOS ANGELES, CALIF. QUAD. (1953)

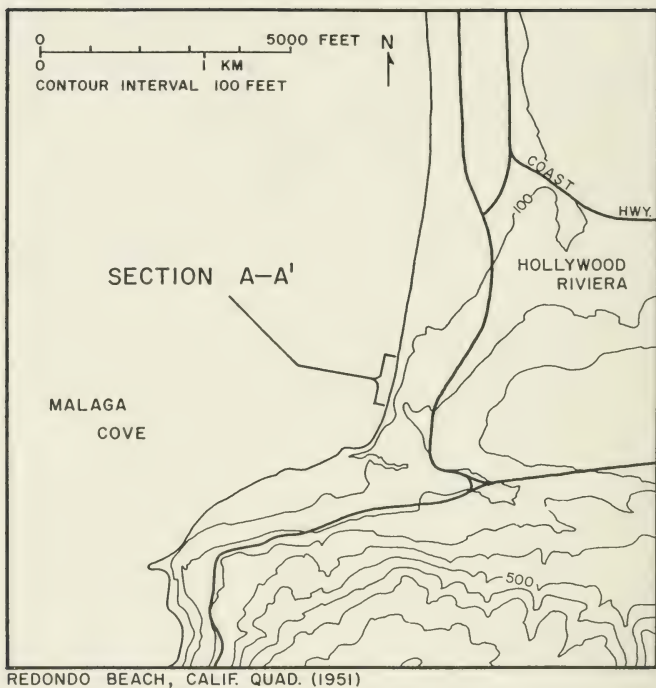
Text-figure 4.—Sample location map of the Repetto Hills section, Los Angeles County, California.



LOS ANGELES QUAD. (1953)
HOLLYWOOD QUAD. (1953)

Text-figure 5.—Location map of the Bunker Hill section, Los Angeles County, California. Samples originally were collected and described by Martin (1952).

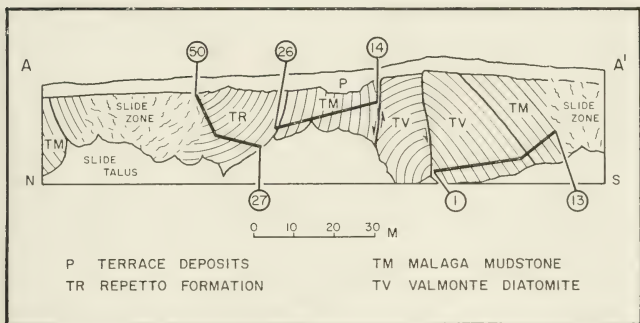
exhibiting low depositional rates (Emery, 1960, p. 212; Palmer, 1964). The section is located on the northwestern flank of the Palos Verdes Hills (Text-figs. 1, 6, 7), an area which has represented a positive anticlinal feature since late Miocene time (Woodring, Bramlette, and Kew, 1946; Barbat, 1958; Bandy, Ingle, and Resig, 1964). The Malaga Mudstone and Valmonte Diatomite members of the Monterey Shale conformably underlie the Repetto Formation in this section; both these units are classically considered upper Miocene and represent a radiolarian and



Text-figure 6.—Location map of the Malaga Cove section, Los Angeles County, California.

diatomite facies essentially barren of Foraminifera. A sample from the basal Malaga Mudstone (U.S.G.S. locality 24 of Woodring, Bramlette, and Kew, 1946) exposed near San Pedro served to establish foraminiferal trends within a portion of these units (Appendix).

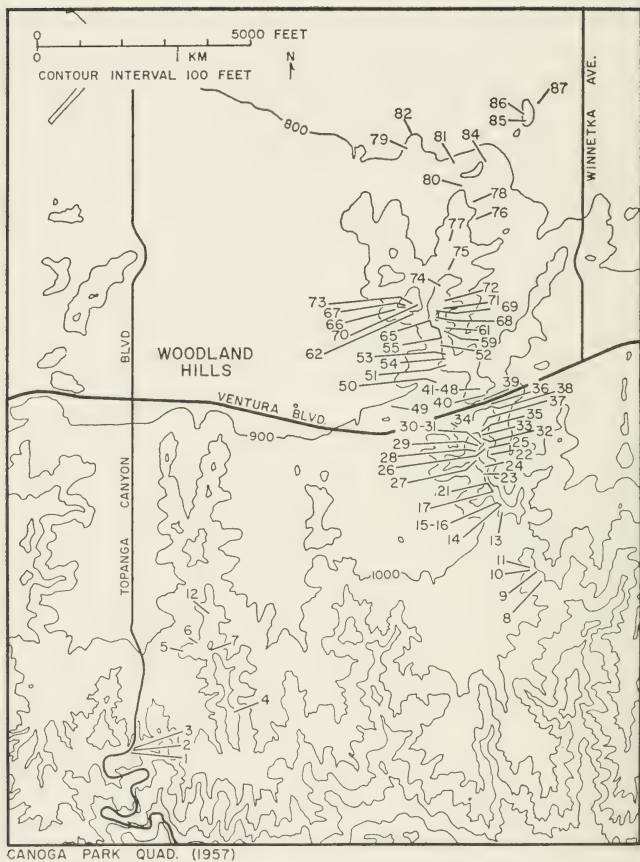
Two sections were selected within upper Miocene sediments of bathyal origin exposed on the northern flank of the Santa Monica Mountains and in the San Fernando Basin (Text-figs. 8, 9). These strata provide faunas representative of latest Miocene time as well as part of the early Pliocene. A preliminary report on the paleoecology of these sections was presented



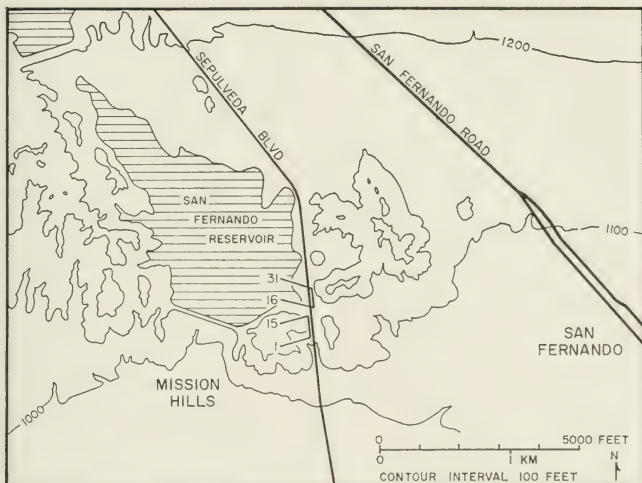
Text-figure 7.—Location of sample traverses within the section of Miocene and Pliocene strata exposed in the sea cliff at Malaga Cove. Section modified from Woodring, Bramlette, and Kew (1946).

earlier (Ingle, 1963b). The 900 meter Woodland Hills section (Text-fig. 8) includes the upper portion of the type section of Kleinpell's (1938) Mohnian Stage. The stratigraphy of this section was originally described by Hoots (1931). Later, Sullwold (1960) studied the sedimentologic properties of a number of massive sand units within Mohnian sediments of the Modelo Formation and concluded the area formed a part of a large submarine fan during late Miocene time (the Tarzana Fan). Diatomaceous shales, laminated diatomite, and massive radiolarian mudstones characterize that portion of the Modelo Formation assigned to the Delmontian Stage (uppermost Miocene) of Kleinpell (1938). The overlying Repetto Formation is composed of a series of fine sands, sandy silts, and siltstones. The Mission Hills section (Text-fig. 9) traverses a faulted anticlinal sequence composed of approximately 180 meters of laminated diatomite assigned to the Modelo Formation overlain by a 250 meter unit of massive arkosic sands and silts mapped as Repetto Formation by Oakeshott (1958).

Planktonic trends during the late Pliocene were established within a section of the Pico Formation exposed in Balcom Canyon of Ventura County (Text-fig. 10) and in samples from an exposure of the San Diego Formation at Pacific Beach near San Diego (Text-fig. 11). Yeats (1965) recently discussed the sedimentary history of the Pico Formation



Text-figure 8.—Sample location map, Woodlands Hills section, Los Angeles County, California.



SAN FERNANDO QUAD. (1953)

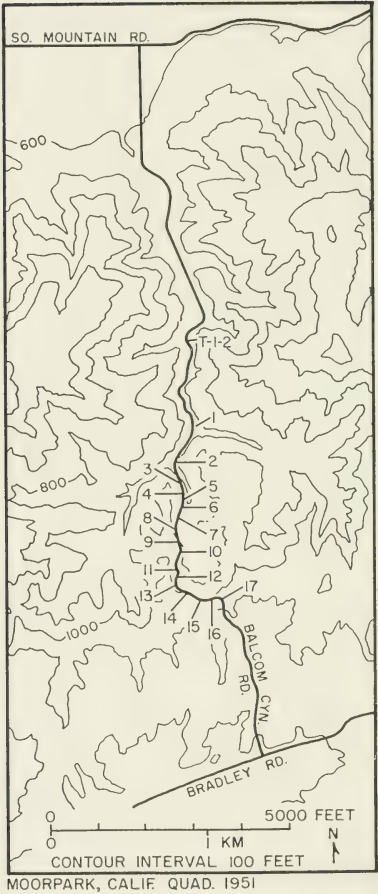
Text-figure 9.—Sample location map, Mission Hills section, Los Angeles County, California.

within that portion of the Ventura Basin which includes the exposures in Balcom Canyon. Yeats (1965) deduced that the formation represents sediments deposited on the shelf and slope of the Pliocene Ventura Basin.

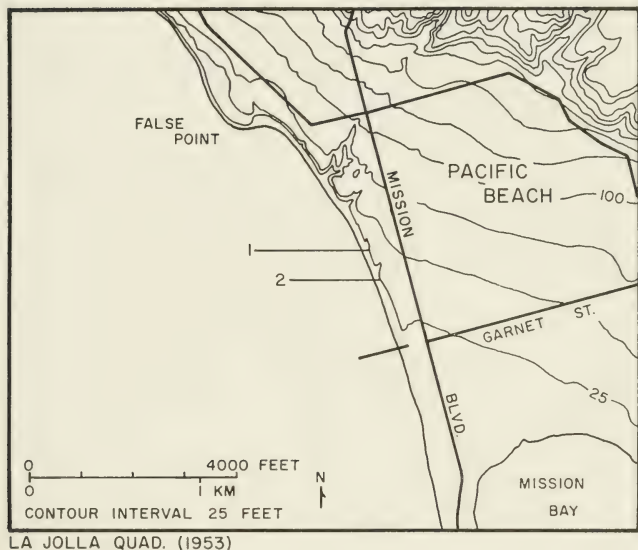
The approximately 110 meter section of San Diego Formation exposed at Pacific Beach (Text-fig. 11) consists of a gently dipping sequence of highly fossiliferous conglomerates, sands, and silty sands deposited in an outer shelf environment. This formation has traditionally been assigned a middle Pliocene age (Hertlein and Grant, 1944; Oakeshott, Jennings, and Turner, 1954), however, Allison (1964) recently placed at least part of the formation within the early Pleistocene.

In addition to the sections and spot samples listed above, frequent reference is made to the 925 meter section of Miocene to lower Pleistocene sediments exposed at Newport Mesa (Text-fig. 1) described in earlier reports (Ingle, 1962, 1963a).

Trends in the distribution of Recent planktonic Foraminifera from



Text-figure 10.—Sample location map, Balcom Canyon section, Ventura County, California.



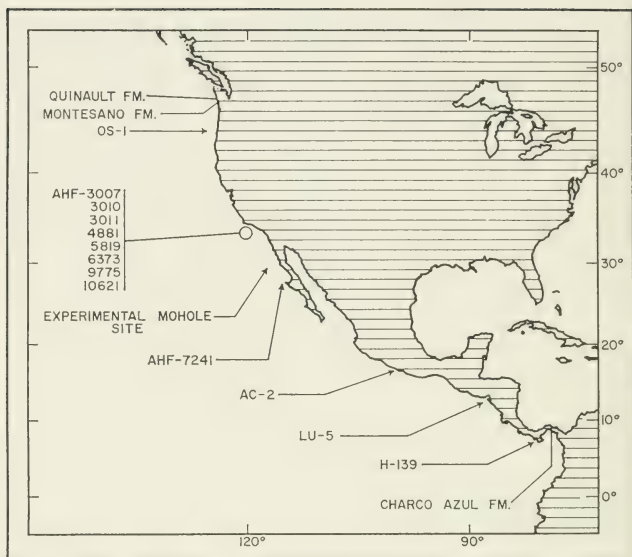
Text-figure 11.—Location map of spot samples collected from the San Diego Formation exposed in sea cliff at Pacific Beach, San Diego County, California.

the marginal eastern North Pacific were established in a series of sediment samples collected off the Baja California peninsula, southern California, and Oregon (Text-fig. 12; Appendix Table 5).

FIELD AND LABORATORY PROCEDURES

Samples collected for this study were plotted on existing U.S.G.S. topographic maps (Text-figs. 4-11). Traverses were surveyed by pace or tape and Brunton compass. Where samples were obtained from more than one continuous sequence, adjacent sections were aligned by extension of strike (Text-figs. 4, 8). Stratigraphic thicknesses were resolved graphically.

Because of soil and climatic conditions in southern California, Foraminifera are often leached from outcrops of a sandy or silty nature whereas



Text-figure 12.—Location of Recent sediment samples utilized and position of pertinent upper Tertiary sections mentioned in the text.

preservation is good in clayey or diatomaceous rocks. Due to this problem samples were not taken at predetermined intervals and hand lens examination was made of outcrop material in order to find samples containing Foraminifera. This process is reflected in the highly variable sample intervals within each section. Leaching is particularly extensive in the lower portion of the type Repetto Formation (Text-fig. 4). The Repetto Formation exposed at Malaga Cove represents an exception, as Foraminifera are abundant throughout (Text-fig. 7). However, a relatively large gap occurs in the sample sequence in the upper portion of the section due to inaccessibility of outcrop on a cliff face. In all cases samples were taken at least 0.25 to 0.5 meter below the outcrop surface. Samples from the Bunker Hill section (Text-fig. 5) were originally collected by Lewis Martin (1952) and deposited in the Micropaleontology Laboratory, University of

Southern California. Unwashed portions of Martin's (1952) original samples were processed for this study as described below. Collection of the Newport Mesa section (Text-fig. 1) was previously described (Ingle, 1962).

Lithologies illustrated on stratigraphic columns are from outcrop descriptions with the exception of the Bunker Hill section which was adapted from Martin (1952). Where lithology consisted of repeated sequences ascribed to turbidity currents or mass movement of sediments (graded bedding, convolute bedding, flame structures), a special symbol is used rather than attempting to delineate each feature graphically. Formation boundaries are based on distinct lithologic breaks and are identical to those of Woodford, Schoellhamer, Vedder, and Yerkes (1954), Woodring, Bramlette, and Kew (1946), Hoots (1931), and Oakeshott (1958). One exception occurs in the Woodland Hills section. The upper 210 meters of this section consist of sands, sandy silts, and clayey silts whereas the underlying portion of the section consists of mudstones, diatomaceous shale with interbedded sands and sandy silts. Moreover, the upper portion contains a micro-and macrofauna of early Pliocene age. Consequently the upper 210 meters of the Woodland Hills section were mapped as part of the Repetto Formation.

Recent samples utilized (Text-fig. 12) were obtained from collections filed in the Micropaleontology Laboratory, University of Southern California. These samples were originally obtained by Campbell grab, Dietz-La Fond sampler, or Phleger corer aboard the R. V. *Velero IV* of the Allan Hancock Foundation (Appendix Table 14). Bathymetric classification of marine environments utilized during this investigation is given on Text-figure 13.

A 50 to 400 gram portion (dry weight) of each sample was soaked in water and washed through a 250 mesh (0.061 mm openings) Tyler screen. Weight of sample washed varied according to lithology and abundance of Foraminifera. Sands, sandy silts, sandy clayey silts, and diatomites were easily disaggregated in water with agitation and heat. Massive mudstones required crushing and treatment with kerosene; material which failed to break down was separated, dried, and its weight subtracted from the original sample weight. After washing, samples were dried and foraminiferal tests were separated from mineral grains by flotation on perchlorethylene. Good separations were obtained for most samples, however, in some cases significant percentages of Foraminifera and radio-

larians did not float due to replacement, filling, or broken tests. In all cases a separate count was made of Foraminifera and radiolarians within concentrates and in residues. Samples were not treated separately for extraction of radiolarian tests because good recovery was obtained during concentration of foraminiferal tests.

Benthic and planktonic foraminiferal populations of each sample were counted separately. A modified Otto microsplitter was used to obtain practical but statistically significant fractions of 200 to 300 benthic or planktonic individuals (Phleger, 1960, p. 34). The entire planktonic and benthic population within a sample was counted when total specimens numbered less than 200. After counting each sample fraction, the entire sample was scanned for species not present in the counted fraction; this process was repeated for both benthic and planktonic populations. Relative abundances of Foraminifera are presented as percentage of the total planktonic or benthic population in a sample. Samples utilized in this study are on file in the Micropaleontology Laboratory of the University of Southern California.

PREVIOUS WORK

GENERAL

Despite the profusion of fossil remains within upper Tertiary marine and terrestrial sequences in southern California, the Miocene-Pliocene boundary remains in dispute (Natland, 1948; Durham, Johns, and Savage, 1954; Durham, 1954; Ingle, 1962).

Early workers utilized mollusks and echinoderms to subdivide and map the upper Tertiary rocks of California (Gabb, 1869; Cooper, 1888; Arnold, 1903, 1909; Grant and Gale, 1931; Loel and Corey, 1932; and many others). These studies naturally emphasized deposits rich in shelf depth and strand line assemblages. Although some investigators (*e.g.*, Woodring, 1938) eventually subdivided deeper water facies on the basis of mollusks, stages based on assemblages of benthic Foraminifera have come to constitute the most widely used subdivision of the Miocene through Pleistocene marine sequence.

USE OF BENTHIC FORAMINIFERAL STAGES

In 1938 Kleinpell issued a report in which type sections and faunal descriptions were given for a seven-fold division of the marine Miocene at the stage level. Kleinpell's work has become of classic importance to

subsequent workers. Moreover, Kleinpell's stages have since been recognized in Miocene strata exposed from Central America (Bandy, 1966a) north to Alaska (Rau, 1963). Later, Natland (1952) subdivided the marine Pliocene and early Pleistocene of southern California into four stages based on benthic Foraminifera (Text-fig. 3). Faunas assignable to these stages have been recognized from the Baja California area (Natland, 1950) north to Washington (Fowler, 1965). The Miocene-Pliocene boundary is traditionally placed between Kleinpell's (1938) Delmontian Stage and Natland's (1952) Repettian Stage (Text-fig. 3).

The benthic fauna of at least a portion of one of the type areas of the Delmontian Stage (Kleinpell, 1938, p. 134) is the product of an oxygen deficient environment within a middle bathyal closed basin as indicated by a series of laminated diatomites (Hülsemann and Emery, 1961; Harman, 1964; Calvert, 1964). This condition is reflected by the morphology of indigenous benthic Foraminifera such as *Bolivina rankini*, *Bolivina seminuda*, and several other species which possess extremely thin translucent tests (Harman, 1964). Natland's (1952) Repettian Stage is characterized by a lower bathyal fauna including *Melonis pompilioides* and *Bulimina rostrata* (Text-figs. 3, 13). The exotic nature of part of the type Delmontian Stage fauna and environment and the strict bathymetric requirements of the type Repettian Stage preclude their common occurrence in successive conformable stratigraphic units. This is borne out in the continuous sequence of lower bathyal sediments in the central Los Angeles Basin; in the absence of any better criterion, micropaleontologists simply place the boundary at the first occurrence, stratigraphically down-section, of a single benthic species, *Rotorbinella* (?) *garveyensis* (Wissler, 1941; Wissler and Crawford, 1948; Natland and Rothwell, 1954; Brooks, 1965). This species is absent from upper bathyal and shelf depth faunas. In both cases the boundary is ecologically controlled.

TIME TRANSGRESSIVE NATURE OF BENTHIC ASSEMBLAGES

The use of stages based on provincial benthic faunas has continued despite the ever-growing body of knowledge concerning the ecology and distribution of living faunas which casts doubt on their reliability as truly chronologic indices. It is apparent from studies of living faunas that vertical changes in assemblages of benthic Foraminifera within a section are primarily a response to varying bathymetry. Linked with this parameter are faunal variations brought about by changes in water temperature with

time, and the existence of even more exotic controls such as oxygen deficient ambient water.

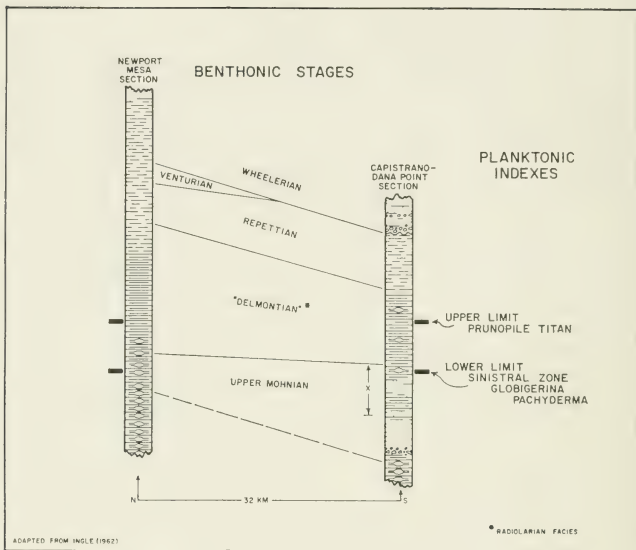
For example, assemblages from the lower to upper Miocene stages of Kleinpell (1938) exhibit decreasing dominance of genera and species characteristic of the Recent Panamanian province environments off Central America and the Gulf of California. These variations reflect a progressive cooling of bottom water during the Miocene (Kleinpell, 1938; Bandy and Arnal, 1957; Bandy, 1961; Bandy and Rodolfo, 1964). Furthermore, there is progressive latitudinal restriction of tropical-subtropical elements within each stage. Species of *Siphogenerina* and *Valvulineria* characterize Saucian Stage assemblages as far north as Alaska (Rau, 1963). However, subtropical species characteristic of portions of the upper Miocene Mohnian Stage in California are absent from faunas assigned to this stage in Washington (Fowler, 1965).

In addition to the above it has been demonstrated that variation in Miocene foraminiferal biofacies commonly reflect changes in paleobathymetry analogous to modern biofacies trends with depth (Pierce, 1956; Bandy and Arnal, 1960; Ingle, 1962; Bandy and Kolpack, 1963; Fowler, 1965).

Granting that a number of useful benthic species are restricted vertically within many Miocene sections in separate basins distributed along the Pacific margin of North America, irregular tectonic and sedimentary control of bathymetry within each basin together with indicated variations in paleo-water temperature lead one to speculate that many of these ranges may not be consistently time equivalent. Considering the above evidence it further seems reasonable that variations in bathymetry within separate basins together with a latitudinally controlled temperature gradient could have allowed benthic faunas characteristic of at least two successive Miocene stages to have existed simultaneously. In light of this possibility it is interesting to note that Fowler's (1965) boundary between the Delmontian and Mohnian Stages within the Montesano Formation coincides with the approximate boundary between benthic faunas characteristic of bathyal depths and those characteristic of a shelf depth environment.³

It seems reasonable to assume that at least a portion of the shelf deposits ("Mohnian") were accumulating at the same time dissimilar sediments and microfaunas ("Delmontian") were being deposited in a conterminous bathyal environment duplicating relationships observed to-

³ Fowler's (1965) *Uvigerina hispidocostata* fauna and *Nonionella* sp. and *Bulminella elegantissima* faunas respectively.



Text-figure 14.—Planktonic correlation of bathyal upper Tertiary sequences within the Capistrano embayment, Orange County, California, after Ingle (1962, 1963a). Alignment of sections on presumably isochronous surfaces illustrates that the traditional Miocene-Pliocene boundary between Delmontian and Repettian stages is time-transgressive in this embayment. "Lower Pliocene" Repettian benthic faunas appeared earlier in the Capistrano area than at Newport Mesa. The thickness of upper Mohnian Stage sediments introduced instantaneously by turbidity currents at Capistrano is shown by "x."

day (Bandy, Ingle, and Resig, 1964c, 1965b). Moreover, Natland (1950, p. 4) in a study of Pliocene faunas from the Gulf of California area was prompted to write, "Many of the abundant Gulf Pliocene forms are also abundant in the upper Miocene of California. Such species as *Bolivina parva*, *Bulimina* cf. *uvigerinaformis*, and *Virgulina californiensis* are not found younger than Upper Miocene in southern California . . . the abundant species *Bulimina* cf. *uvigerinaformis*, which in southern California is an excellent marker for the lower Mohnian, is abundant in most Gulf Pliocene samples."

More lucid and specific evidence of the time transgressive nature of benthic stages has been established within the Pliocene and Pleistocene sequence. Generally, the successive appearance of "lower Pliocene" Repettian Stage faunas representing lower bathyal depths through "Pleistocene" Hallian Stage faunas representing shelf depths in any particular series of strata is simply a measure of the local rate of shoaling (Crouch, 1952; Bandy, 1953b; Holman, 1958; Bandy, 1960a). Bandy (1960a) clearly illustrated that bathyal, "upper Pliocene," Wheelerian Stage faunas were living at the same time as outer shelf, "lower Pleistocene," Hallian Stage faunas by aligning sections on time-correlative planktonic horizons.

Finally, Ingle (1962; 1963a) presented evidence defining the time transgressive nature of the traditional Miocene-Pliocene boundary based on benthic foraminiferal stages within the late Tertiary Capistrano Embayment. Using mutually corroborative horizons established on time-correlative planktonic parameters, Ingle illustrated that Repettian Stage faunas appeared much earlier in southern portions of the embayment than elsewhere (Text-fig. 14). Moreover, it was shown that Delmontian Stage equivalents ("uppermost Miocene") existed in one portion of the basin while Repettian ("lower Pliocene") faunas were thriving in shallower areas. Ingle (1962) redefined a Miocene-Pliocene boundary within the embayment on planktonic evidence of a late Miocene period of subarctic surface temperature.

Previous work on planktonic faunas from later Tertiary formations of southern California will be discussed in a later more appropriate section of the report.

PALEOBATHYMETRIC AND PALEOECOLOGIC INTERPRETATIONS

GENERAL

Paleoecologic interpretations of fossil populations were founded on the wealth of detailed information available on the bathymetric distribution of modern species in the marginal eastern Pacific. The analogous relationship between fossil faunas of the southern California Tertiary and those existing in the nearby ocean was first speculated upon by Bagg (1912). In 1933 Natland presented the first comprehensive account of the apparent bathymetric control of benthic faunal groups; additional details were delineated by Crouch (1952) and Bandy (1953a). Quantitative analysis of modern faunas and assorted ecologic parameters from a number of

areas have allowed further refinement of trends (Walton, 1955; Bandy and Arnal, 1957; Resig, 1958; Zalesny, 1959; McGlasson, 1959; Uchio, 1960; Bandy, 1961; Bandy and Rodolfo, 1964; Phleger, 1965). Several investigations have dealt exclusively with faunas from paralic and shelf environments (Reiter, 1959; Resig, 1959; Cooper, 1961; Watkins, 1961; Bandy, 1963a; Bandy, Ingle, and Resig, 1964a, 1964b, 1964c, 1965a, 1965b) whereas others have delineated specific aspects of selected environments (Lutze, 1962; Bandy, 1963b; Harman, 1964; Bandy, 1964). Phleger (1960, 1964) summarized current knowledge regarding modern faunas.

GROSS POPULATION TRENDS

Results of the studies noted above and others have yielded a number of useful quantitative relationships between benthic microfaunal facies and associated environmental parameters which can readily be applied to fossil assemblages (Bandy and Arnal, 1960). The following parameters were measured during the present investigation.

Foraminiferal number.—As defined by Schott (1935) foraminiferal number represents the number of tests per gram of dry sediment. This parameter is equally applicable as a measure of relative abundance in Recent and fossil sediments. Application can be made at the population, generic, or specific level (Bandy, Ingle, and Resig, 1964); furthermore, abundance of any constituent (*i.e.*, mineral grains, shell fragments) of the bottom sediments can be measured in a like manner and comparisons made between samples. Foraminiferal number increases offshore with maximum values at the shelf edge and within upper bathyal depths; numbers decrease into the lower bathyal zone where radiolarians become abundant (Bandy and Arnal, 1960). An exception occurs in deep-sea areas where sediments are composed almost solely of the tests of planktonic Foraminifera. Other areas of unusually high foraminiferal numbers include the top of banks, seamounts, and insular shelves; each of these environments is characterized by a low rate of sedimentation.

Planktonic-benthic ratio.—The ratio of planktonic foraminiferal tests to benthic tests slowly increases across the shelf with a sharp increase of up to 100 fold at the shelf edge and deeper. This significant trend is attributable in part to, (1) the generally variable and unfavorable ecologic conditions for planktonic forms over relatively shallow shelf areas, (2) upwelling of nutrient-rich water and consequent increase in plankton productivity at the shelf edge providing abundant food for planktonic

species, and (3) a longer water column permitting all species to be present (Bandy and Arnal, 1960; Bandy, Ingle, and Resig, 1964c, 1965b; Casey, 1965).

Species diversity.—Studies of Recent faunas have shown that the number of benthic species per sample increases offshore to a maximum in outer shelf to middle bathyal depths; a decrease in number occurs in deeper environments (Bandy and Arnal, 1960). Presumably this trend is a response to optimum conditions for productivity, however, abnormally high species numbers characterize many bathyal samples due to downslope displacement of groups which normally inhabit shoaler areas. Cumulative faunal displacement may explain some of the straight-line relationships between species number and increasing depth presented by Bandy and Arnal (1910). Species number may also be low in restricted basins (Resig, 1958) although foraminiferal numbers in such environments may be high due to low rates of sedimentation. It is also apparent that species number can be significantly affected by the taxonomic philosophy of any particular investigator.

Radiolarian trends.—Radiolarians live stratified in the water column from the surface to depths of over 8,000 meters (Orlov, 1959); number of species and abundance increase with increasing length of the column, hence radiolarian number (number of tests per gram of dry sediment) increases with depth. Maximum values generally are recorded in sediments deposited deeper than 2,000 meters, along with abundant hexactinellid sponge spicules and relatively rare foraminiferal tests (Bandy, 1953a; Bandy and Arnal, 1957, 1960; Bandy and Rodolfo, 1964). The relative abundance of radiolarian tests *versus* foraminiferal tests, therefore, constitutes an excellent tool in the identification of middle bathyal to abyssal deposits (Ingle, 1962; Bandy and Kolpack, 1963); conversely, low rates of sedimentation may lead to increased concentrations on a test-per-unit-weight basis in closed basins or in areas of exclusively pelagic sedimentation.

Another useful trend exhibited by radiolarians is their systematic variation in morphology with temperature and depth (Haeckel, 1887; Campbell, 1954; Orlov, 1959, p. 618-642; Ingle, 1962; Casey, 1965). Of particular interest is the fact that massive, heavy, spherical members of the suborder Spumellaria appear to be restricted to depths between 1,000 and 8,000 meters; specimens of greatest diameter generally occur at the deepest horizons. Even on a specific level there is a tendency for a par-

ticular species to grow to its maximum diameter in the deepest portion of its vertical range (Popofsky, 1913). Consequently, diameters of the largest and smallest spumellarians in samples of this study were noted in addition to noting composition of the radiolarian faunas in terms of percentage of Nassellaria and Spumellaria.

In addition, presence or absence of the spumellarian, *Prunopyle titan*, was recorded because this species appears to have a restricted range within a portion of the upper Miocene of southern California (Campbell and Clark, 1944; Ingle, 1962) and possibly other areas (Hays, 1965). Usefulness of this species is limited as it seems to occur only in middle bathyal to abyssal deposits suggesting a restricted living range within the later Miocene water column.

BENTHIC FAUNAL GROUPS

Although the particular parameters causing benthic species of Foraminifera to live exclusively within specific depth horizons have yet to be positively identified (Phleger, 1964), the consecutive appearances of characteristic faunas from shallow to deep water offers an unparalleled paleoecologic tool. Curves of the cumulative frequency of a number of selected benthic species with increasing depth demonstrates this trend (Text-fig. 13). It must be noted, however, that the upper bathymetric limits of some species vary from area to area, whereas many other species occupy identical upper depth limits regardless of other differences in ecologic setting (Bandy and Echols, 1964; Bandy and Chierici, 1964). Despite these complications, reasonable paleobathymetric reconstructions have been made utilizing analogous quantitative relationships between Recent and Tertiary faunas within the same zoogeographic provinces (Natlund, 1952; Bandy, 1953b; Ingle, 1962; Bandy and Kolpack, 1963; Fowler, 1965). Although analogy with modern distributions becomes increasingly difficult at the specific level in pre-Pliocene sediments, Bandy and Arnal (1960) have demonstrated how use of a homomorphic and isomorphic relationships with living species overcomes this problem. This concept has been further strengthened by Bandy's (1960b) correlation of test morphology and modern environments. Moreover, some living species of known bathymetric tolerance occur as fossils as far back as the Eocene (Bandy and Kolpack, 1963).

During this investigation the common benthic Foraminifera within the upper Miocene and Pliocene sediments studies were organized into five

faunal groups representative of inner shelf to lower bathyal environments (Table 1). A sixth group was created for species commonly found within laminated diatomites and analogous with faunas found in low oxygen environments today (Harman, 1964). These species are characterized by thin-transparent to half-opaque-half-translucent tests reflecting marginal oxygen conditions that inhibit production of calcium carbonate (Harman, 1964). *Suggrunda eckisi* appears to be an especially outstanding index of these conditions within both modern (Harman, 1962, 1964) and ancient (Ingle, 1962) sediments. Smooth, thin-tested forms of *Uvigerina bootsi* and related subspecies may also have inhabited restricted basins, however, they also occur in sediments indicating normal oxygen values. The majority of species utilized in paleobathymetric interpretation are living today in the marginal eastern Pacific. Extinct species were assigned a probable depth habitat consistent with their morphology following the concepts outlined by Bandy (1960b), Bandy and Arnal (1960), Harman (1964), and their persistent faunal association.

TABLE 1. Dominant Benthic Faunal Groups

All species assigned to each group are not present in all sections. Principal references used in classification were Walton (1955), Bandy (1953a), Bandy and Arnal (1957), Bandy (1961), Bandy (1963b), Bandy and Rodolfo (1964), and Fowler (1965).

Group 1-A. Dominant Inner Shelf Species: 0-50 meters

Ammonia beccari tepida
*Bolivina vughani*¹
*Buliminella elegantissima*²
Buccella frigida
Buccella tenerrima
*Cancris auricula*³
Cibicides lobatus
Elphidium crispum
Elphidium incertum
Elphidium poeyanum translucens
Nonionella basispinata
Nonionella miocenica stella
Quinqueloculina akneriana
Quinqueloculina angulostriata
Quinqueloculina costata
Quinqueloculina lamarckiana
Trochammina inflata
Trochammina pacifica

Group 1-B. Dominant Outer Shelf Species: 50-150 meters

Angulogerina baggi
Bolivina acutula
*Bolivina tongi filicostata*³

*Bulimina marginata denudata*²
*Buliminella curta*³
*Buliminella ecuadorana**
Cassidulina minuta
*Discorbinella valmonteensis**
Gaudryina arenaria
*Hanzawaia nitidula*³
*Uvigerina juncea*⁴

Group 2. Dominant Upper Bathyal Species: 150-600 meters

*Angulogerina angulosa*⁴
*Bolivina acuminata*⁴
*Bolivina interjuncta*⁴
Bolivina pacifica
Bolivina pseudoplicata
*Bolivina spissa*⁵
*Bolivina torqueata*³
*Buliminella subfusiformis**
*Cassidulina barbarana**
Cassidulina californica
*Cassidulina limbata*⁴
Cassidulina lomitensis
*Cassidulina modeloensis**
Cassidulina tortuosa
Cassidulina translucens
Cassidulina subglobosa quadrata
Cassidulina subglobosa subglobosa
Chilostomella czizeki
Chilostomella ovoidea
*Cibicides mckannai*⁴
*Epistominella subperuviana*⁴
Globobulimina pacifica
Gyroidina altiformis
Pullenia malkinae
Pullenia salisburyi
*Uvigerina kernensis**
*Uvigerina peregrina*⁵
*Uvigerina segundoensis**

Group 3. Dominant Upper Middle Bathyal Species: 600-1,500 meters

Bolivina argentea
*Bolivina marginata multicostata**
*Bolivina sinuata**
*Bolivina subadvena sulphurensis**
Bulimina affinis
*Bulimina subacuminata**
*Bulimina subcalva**
*Cassidulina cushmani*⁶
*Cassidulina delicata*⁶
*Epistominella pacifica-smithi*⁶

Group 4. Dominant Lower Middle Bathyal Species: 1,500-2,500 meters

Bulimina pagoda hebespinata
Melonis barleanus

Stilostomella adolphina
Stilostomella advena
Uvigerina hispida
*Uvigerina hispidocostata*⁶
Uvigerina bootsi and variants (?)^{*}
*Uvigerina proboscidea*⁶
*Valvulineria araucana araucana*⁶
Valvulineria araucana malagaensis^{*}

Group 5. Dominant Lower Bathyal Species: 2,500 meters +

*Bulimina rostrata*¹
Gyroidina gemma
Gyroidina soldani
Melonis pompilioides
*Pullenia bulloides*¹
Uvigerina senticosa

Group 6. Restricted Basin Impoverished⁸ Species: Greater than⁹ 400 meters

Bolivina benedictensis^{*}
Bolivina brevior^{*}
Bolivina hughesi^{*}
Bolivina obliqua^{*}
Bolivina pseudospissa^{*}
Bolivina rankini^{*}
Bolivina seminuda foraminata
Bolivina seminuda seminuda
Suggrunda eckisi
Uvigerina bootsi (?)

¹ Bimodal distribution; shelf and bathyal depths.

² Bimodal distribution; inner shelf and shelf edge.

³ Abundant to common in subtropical to tropical shelf environments today (see Bandy and Arnal, 1958; Bandy, 1961; Bandy, 1963b).

⁴ Transitional distribution from outer shelf to upper bathyal depths; abundant at the shelf edge.

⁵ Transitional distribution from upper bathyal to upper middle bathyal depths.

⁶ Transitional distribution from upper to lower middle bathyal depths.

⁷ Transitional distribution from lower middle bathyal to lower bathyal depths.

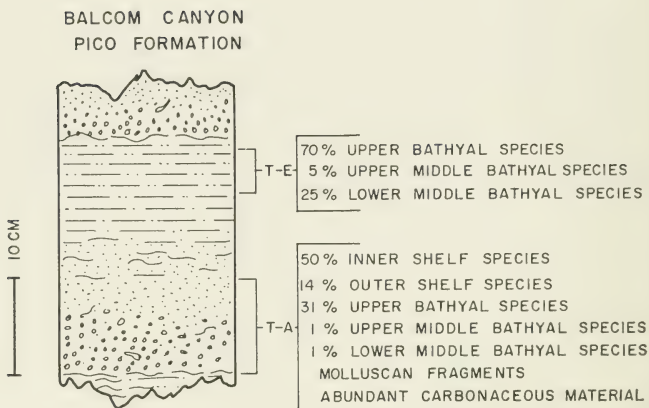
⁸ Test morphology of indigenous species reflects inability of animal to produce calcium carbonate due to low oxygen content of ambient water (see Harman, 1964).

⁹ Sill depth of closed basin assumed to be within critical portion of the oxygen minimum zone (200-1,300 meters in depth); basin plain may be up to 900 meters below effective sill depth (see Emery, 1960, p. 109-110; Calvert, 1964).

^{*} Presumably extinct species.

DISPLACED SPECIES

Firm evidence is now available documenting the downslope gravity transport of sediments and animal remains in Recent to Pre-Cambrian marine environments (Emery, 1965). Early work by Natland and Kuenen (1951) and Phleger (1951) established the utility of benthic Foraminifera



Text-figure 15.—Distribution of benthic Foraminifera within a turbidite sequence in the Pliocene Pico Formation, Balcom Canyon. Middle bathyal species are presumed to represent the indigenous fauna.

as tracers of displaced marine sediments. Theoretically, the percentage of displaced species should increase progressively downslope as faunal elements from successively deeper environments are mixed by sediment slippage. Studies in the Gulf of California have substantiated this concept; an average of over 70 percent of basin and slope faunas were found to be displaced from shallower horizons whereas 0 to 49 percent of shelf faunas were found to be displaced (Bandy, 1961). This process is naturally accelerated in submarine canyons and on adjacent fans due to more frequent, direct, and rapid transport from extremely shallow areas to bathyal depths (Gorsline and Emery, 1958; Bandy, 1964a). An analysis of two samples from a typical turbidite sequence in the Pliocene Pico Formation serves to emphasize the various characteristics of turbidite horizons common in bathyal Miocene and Pliocene sediments of southern California (Text-fig. 15; Table 2).

A 24 centimeter thick sequence was selected within the Pico Formation which exhibits at least four of the five characteristic sedimentary intervals of an ideal turbidite unit according to Bouma (1962, p. 49). Samples were taken from the graded interval (Ta) and the so-called pelitic interval

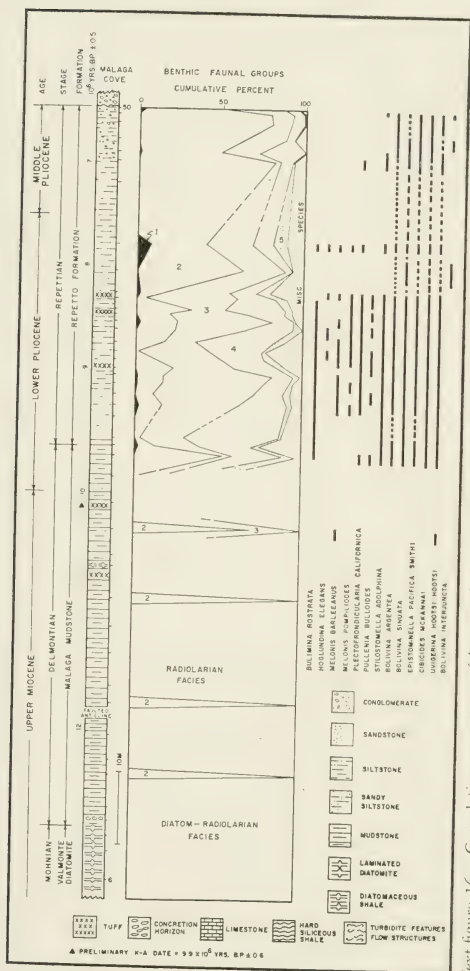
(Te). Faunal composition of the graded sand strikingly parallels that described from modern deep-water sands by Bandy (1964). The difference in species number and character of each sample suggests an inverse time-of-arrival at the site of deposition; shallowest elements arrived initially, enclosed within the coarsest sediments, whereas abundant elements from upper bathyal depths arrived last within sediments of lower settling velocity. Assuming the middle bathyal species represent the indigenous fauna, 70 percent of the fauna within the pelitic layer is displaced and 95 percent of the graded interval fauna is displaced. Important characteristics exhibited by the graded interval but absent from the pelitic interval include (1) dominance of shelf species (2) marginal values of the indigenous middle bathyal fauna (3) abundant carbonaceous trash, and (4) abundant molluscan remains and common ostracodes. Interestingly, planktonic species comprise 11 percent of the total population in the graded interval but are absent in the pelitic interval. This accords with Bandy's (1964) finding that deep-water sands commonly contain a relatively high percentage of planktonic specimens displaced from areas of higher planktonic number whereas the number of planktonic tests in indigenous basin sediments is commonly low. Finally, it is also important to note that 42 percent of the total foraminiferal population in the graded interval (Ta) consisted of reworked Miocene species (not listed in Table 2); these specimens were easily identified by their filled tests, abraded surfaces, and patina of hydrous iron oxide. Reworked species were assumed to have been eroded from outcrops adjacent to the inner shelf and from submarine exposures on the shelf. The large number of radiolarians in the graded interval are also anomalous and represents reworked Miocene material; again tests were broken, filled, and stained.

During this investigation elements of the deepest faunal group (Table 1) present in any sequence were assumed to represent the indigenous fauna. Representatives from all shallower faunal groups were assumed to be displaced. Inasmuch as all species identified in each sample were not included within faunal group (Table 1) estimated percentages of displaced species are thought to constitute minimum values. Not surprisingly, bathyal faunas were found to be dominated by displaced specimens with indigenous faunal elements commonly amounting to less than 20 percent of the total fauna. Exceptions occurred occasionally in sediments deposited within closed basins and commonly in sediments deposited at shelf depths consistent with modern patterns (Bandy, 1961).

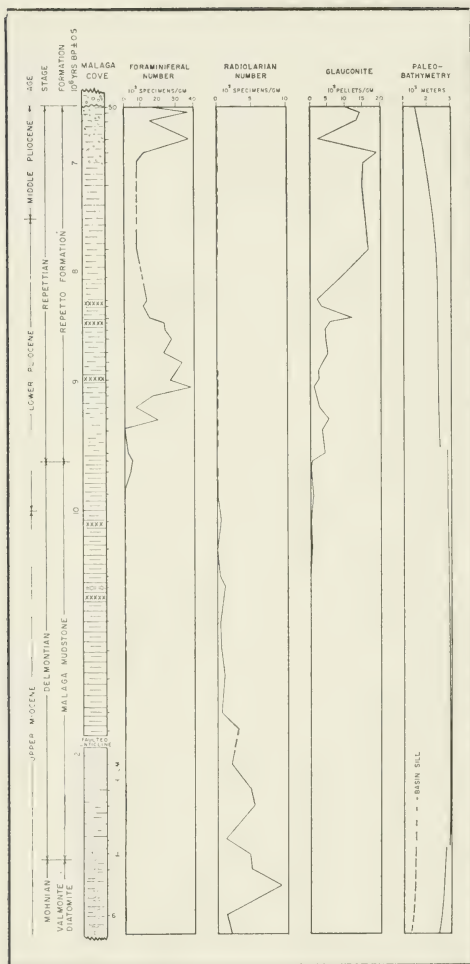
MALAGA COVE SECTION GENERAL STRATIGRAPHY

The Malaga Cove section is composed of three basic units (Text-figs. 16, 17). The stratigraphically oldest portion is composed of an 11 meter thickness of laminated diatomite assigned to the Valmonte Diatomite Member of the Monterey Shale by Woodring, Bramlette, and Kew (1946). The diatomaceous sequence is conformably overlain by a 13 meter thick series of massive, pink-brown mudstones assigned to the Malaga Mudstone Member of the Monterey Shale; the transition zone between these two lithologic units contains a zone of limestone concretions. A faulted anticlinal sequence (Text-figs. 7, 16) separates the basal portion of the Malaga Mudstone from a 35 meter thickness within the upper portion of the unit. Lithology of the younger sequence differs only slightly from the basal portion by the presence of a thin diatomaceous horizon and two vitric tuffs (Text-fig. 16). Woodring, Bramlette, and Kew (1946) estimated the total thickness of the Malaga Mudstone at slightly over 90 meters; thus an approximately 45 meter unit of the member is missing within the fault gap (Text-fig. 16). As noted by Woodring, Bramlette, and Kew (1946), the boundary between the Malaga Mudstone and the overlying glauconitic silt unit is rapid and conformable; in places the transition zone includes alternating thin sands, mudstones, and silts. The overlying 46 meter sequence is an unusual series of compact glauconitic silts traditionally assigned to the Repetto Formation. The mid-portion of the Repetto Formation is characterized by three vitric tuffs (Text-fig. 16); each tuff averages less than eight centimeters in thickness. The lower five meters of the formation includes at least two discontinuous 0.25 meter thick sands. Another striking feature is the increasing frequency of rounded pebbles and angular chips of glaucophane schist within the upper 10 meters of the unit. This unique rock type is locally termed "Catalina schist" and occurs as the basement rock only in the western Los Angeles Basin, Palos Verdes Hills, and Catalina Island 40 kilometers southwest of Malaga Cove although evidence indicates it was exposed over a much larger area to the west during the middle Miocene (Woodford, 1925).

Benthic Foraminifera within the Valmonte Diatomite are characteristic of the upper Mohnian Stage; two faunas from the basal Malaga Mudstone have been assigned to the Delmontian Stage along with the overlying foraminiferan barren, radiolarian-rich mudstone (Woodring, Bramlette, and Kew, 1946); benthic faunas within the Repetto Formation are typical



Text-figure 16.—Cumulative percentage of benthic faunal groups and absolute ranges of selected benthic species within the Malaga Cove section. Key to benthic faunal groups is as follows; 1) shelf species 2) upper bathyal species 3) upper middle bathyal species 4) lower middle bathyal species 5) lower bathyal species. Lithologic code applies to all sections in this report; no one section contains all possible symbols. Note that samples 1 to 5 are omitted from the columnar section.



Text-figure 17.—Foraminiferal number, radiolarian number, glauconite abundance, and estimated paleobathymetry within the Malaga Cove section.

of the Repettian Stage of Natland (1952), (Text-fig. 3). Alignment of the radiometric scale (Text-fig. 16) is based in part on a K-Ar date of 11.5×10^6 years B.P. (before present) obtained by Yeats (1965) on tuff within the upper Miocene Modelo Formation, the radiometric scale given by Bandy (1966), and a K-Ar date⁴ of 9.9×10^6 years B.P. (± 0.6) obtained from an ash within the upper Malaga Mudstone (Text-fig. 16). An adjustment in scale was made to allow for the relatively slower deposition of the glauconitic silts; obviously this estimated scale is subject to correction as more dates become available. Division of the lower and middle Pliocene was based on planktonic indices presented in a later section. It is important to note that the lower Pliocene portion of the Repetto Formation is contained within 25 to 30 meters whereas equivalent strata in the central Los Angeles Basin total more than 1,900 meters (Yerkes, McCulloh, Schoellhamer, and Vedder, 1965).

LITHOFACIES AND BIOFACIES TRENDS

The sequence of laminated diatomites and conformably overlying mudstone in the lower portion of the Malaga Cove section are both characterized by (1) rare occurrence of Foraminifera and (2) extremely high radiolarian numbers. Essentially identical lithofacies and biofacies have lately been delineated within existing basins in the Gulf of California (Byrne and Emery, 1959; Bandy, 1961; Van Andel, 1964; Calvert, 1964) and off southern California (Emery, 1960; Hülsemann and Emery, 1961).

Radiolaria-diatom facies.—Hülsemann and Emery (1961) and Calvert (1964) described the formation of laminated diatomites in the sea off southern California and in the Gulf of California respectively. However, great thickness of laminated diatomite within the Miocene of California such as the Valmonte Diatomite⁵ (Text-fig. 16) requires some detailed speculation.

The principal factors which allow accumulation and preservation of these laminated biogenic sediments are (1) low oxygen content of ambient basin water which inhibits development of a bottom fauna capable of destroying laminae and (2) high plankton productivity in adjacent or overlying waters. Calvert's (1964) work showed that diatomaceous laminae can form on open basin slopes within the oxygen minimum zone. However, in light of the instability of slope sediments with time it would

⁴ Geochron Laboratory sample No. R-0536; date obtained on glass shards.

⁵ Woodring, Bramlette, and Kew (1946) estimated the total thickness of the Valmonte Diatomite at 150 meters or more.

seem more likely that thick units of undisturbed laminated diatomite such as the Valmonte Diatomite were formed on the subsiding floors of closed basins. Calvert's (1964) work also disclosed that preservation of laminated diatomites is restricted to areas where oxygen content is less than 0.3 ml/l. Curves of dissolved oxygen *versus* depth in Guaymas Basin in the Gulf of California indicate values less than 0.3 ml/l are restricted to depths between 200 and 1,300 meters (Calvert, 1964); this range is slightly narrower in the open ocean (Bruneau, Jerlov, and Koczy, 1953). Thus effective sill depth of a closed basin containing laminated diatomaceous sediments must lie within this bathymetric range in order to maintain the critically low values over the basin floor. In this regard it is pertinent to note that floors of basins off southern California are as deep as 900 meters below their effective sill depth; moreover, physical characteristics of water within each basin are controlled by the character of water at the effective sill depth regardless of floor depth (Emery, 1960, p. 110). These facts imply critically low oxygen values and consequent formation of diatomaceous laminae could prevail at depths as great as 2,100 meters, given the necessary basin configuration by local tectonics.

Although the sequence of Valmonte Diatomite studied at Malaga Cove is characteristically barren of Foraminifera, Woodring, Bramlette, and Kew (1946) provide a checklist of species found at random horizons within the unit at nearby localities. The faunas include *Bolivina hughesi* and other species characteristic of Kleinpell's (1938) upper Mohnian Stage (Text-fig. 3). Of more importance is the fact that these faunas include frequent occurrence of thin-tested *Bolivina seminuda*, *Bolivina pseudospissa* and other species composing faunal group 6 (Table 1) and characterizing low oxygen conditions. These forms are assumed to represent the indigenous basin fauna existing intermittently under marginal conditions. Of greatest abundance are species displaced from normally oxygenated waters above sill depth; deepest elements within the displaced groups include *Bolivina sinuata* and *Valvulineria araucana* suggesting a sill depth within middle bathyal depths. Analysis of a fauna from a diatomaceous horizon within the transition zone between the Valmonte Diatomite and the Malaga Mudstone (U.S.G.S. locality 2-4; Appendix Table 2*) also reveals elements of the indigenous restricted basin fauna. However, the fauna is principally composed of displaced species characteristic of shelf to middle bathyal depths. Middle bathyal species include

* Table 2, see page 283.

TABLE 3. Percentages of diatoms, Foraminifera, Radiolaria, and terrigenous material in selected Gulf of California basins, size range of material scanned (0.25-0.06 mm) in establishing percentages may have caused omission of a significant number of radiolarians in the deeper basins. Basins sediment samples are predominantly coarse clays to fine silts (Van Andel, 1964; Inman, 1952).

Basin	Depth (meters)	Terrigenous Material ²	Foraminifera ²	Diatoms ²	Radiolaria ²
San Pedro Martir	978	25	3	66	8
Sul si Pudes	1,504	31	16	39	6
Guaymas	1,975	44	7	39	17
Carmen	2,818	41	12	45	29
Farallon	3,153	46	14	6	26
Pescadero	3,678	49	2	9	38

¹ Data from Van Andel (1964, p. 293).

² Percent by number within the 0.25-0.06 mm fraction.

Bulimina pagoda hebespinata, *Bulimina subacuminata*, *Uvigerina hispidocostata* and *Valvulinera araucana malagaensis*. Depth limits of the displaced middle bathyal species and lower depth limit of the required critical oxygen values suggest the sill depth of the basin enclosing the Valmonte Diatomite was at 1,000 to 1,300 meters.

High radiolarian numbers up to 9,170/gram within the Valmonte Diatomite (Text-fig. 17) are in part a function of the low specific gravity of the biogenic sediment and a relatively low rate of sedimentation. However, the high percentage of radiolarian tests suggest the basin floor was between 2,000-2,800 meters deep when a comparison is made with existing Gulf of California basins containing high percentages of *both* Radiolaria and diatoms (Table 3).

Radiolarian facies.—The rapid transition from continuous laminated diatomites to the radiolarian-rich Malaga Mudstone indicates that tectonic activity during the late Miocene altered basin configuration in a manner allowing entrance of normally oxygenated water. Several trends within the Malaga Mudstone suggest that during this period of structural adjustment the basin floor subsided rapidly. The Malaga Mudstone is characterized by (1) an almost complete absence of Foraminifera as opposed to random faunas within the underlying Valmonte Diatomite (2) an increase in percentage of terrigenous fine silt and clay (3) comparatively low numbers of diatom frustules and (4) continued abundance of radiolarian tests with a maximum radiolarian number of 5,095/gram in the basal portion of the unit. These characteristics are strikingly similar to lithofacies and biofacies common to basins between 3,000-3,600 meters in depth within the Gulf of California (Table 3).

Trends in the maximum diameter of spumellarians (Appendix Table 8) also indicate a deepening of the basin occurred during deposition of the Malaga Mudstone. Maximum diameter increases from a low of 0.20 mm in the Valmonte Diatomite to a maximum of 0.47 mm in the upper portion of the Malaga Mudstone and decreases again to 0.20 mm in the basal Repetto Formation (Appendix Table 3). Maximum spumellarian diameter reaches 0.50 mm within an adjacent section of Malaga Mudstone in part equivalent to that portion of the unit missing within the fault gap in the measured section (Text-fig. 16). Recalling that spumellarian diameter increases with depth of water this trend corroborates the conclusion that water depth increased significantly during deposition of the radiolarian mudstones. However, occasional thin horizons of laminated diatomite

within the Malaga Mudstone (Text-fig. 16) indicate that circulation was marginal within the basin and that critically low oxygen values occurred for short periods allowing perservation of laminae. Three significant trends occur within the youngest portion of the Malaga Mudstone: (1) radiolarian number decreases from thousands to hundreds per gram (2) maximum spumellarian diameter decreases from 0.37 to 0.23 mm (Appendix Table 8) and (3) glauconite pellets occur in significant numbers of 205-819/gram (Text-fig. 17). Decreasing radiolarian number and spumellarian diameter indicate a shallowing of the basin. Occasional occurrences of displaced upper and middle bathyal Foraminifera indicate that gravity sliding of sediment was active. Introduction of glauconite pellets is also assumed to have occurred by displacement from an adjacent area of low deposition. These pellets represent the initial evidence of the formation of a nearby bottom prominence or banktop along the Palos Verdes uplift during late Miocene time.

Glauconitic-foraminiferal facies.—The narrow but conformable transition from the Malaga Mudstone to the glauconitic silts of the Repetto Formation is marked by: (1) several discontinuous thin sands (2) a reduction in radiolarian number from several hundred to less than one per gram and (3) the abrupt occurrence of significant foraminiferal numbers of several thousand per gram (Text-fig. 17). These rapid variations within less than a meter of strata indicate a disconformity is present between the radiolarian mudstones and glauconitic silts as suggested by Wissler (1943) and Woodring, Bramlette, and Kew (1946).

A lower bathyal foraminiferal fauna characterized by marginal percentages of *Melonis pompilioides* occurs within the basal Repetto Formation suggesting water depths between 2,000-2,500 meters (Text-fig. 16). Even more revealing is the concurrent presence of high percentages of displaced upper and middle bathyal species indicating a much shoaler area was in existence immediately upslope from the site of deposition. This evidence indicates the disconformity between the radiolarian mudstones and glauconitic silts almost certainly was produced by accelerated uplift and folding of the incipient bottom prominence initially produced on a local portion of the basin plain during the late Miocene. Uplift likely occurred along the entire length of the anticlinal trend which forms the Palos Verdes Hills today. This trend can be traced southeast across the San Pedro Shelf (Moore, 1954; Bandy, Ingle, and Resig, 1964c) to Lasuen Bank (Fowler, 1963).

Several trends within the Repetto Formation conclusively establish the site of deposition as the slowly rising flank of a prominent early Pliocene bank somewhat analogous to Tanner Bank off southern California today (Emery, 1960) and modern banks within the Gulf of California (Van Andel, 1964). Important gross characteristics which indicate a low rate of deposition typical of bank tops include: (1) extremely high numbers of glauconite pellets increasing from 4,198/gram in the basal portion to 18,842/gram in the uppermost portion of the unit and (2) variable but extremely high foraminiferal numbers varying from 2,163/gram to 39,376/gram and averaging 19,000/gram throughout the unit. The fact that most of the lower Pliocene is represented by only 25-30 meters of sediment confirms this conclusion.

Foraminiferal faunas within the Repettian glauconitic silts exhibit the following features: (1) planktonic species average less than 1 percent of the total fauna (2) dominant benthic populations are composed almost exclusively of hyaline species and (3) species number varies from 76 to 2 and averages a high 48 due to displaced faunal groups (Appendix Table 3); displaced species average over 80 percent of the total population within most samples (Appendix Table 8). As noted earlier prominent elements of the lower bathyal group constitute the indigenous fauna within the lower half of the 46 meter unit. Lower middle bathyal species represent the deepest elements within the upper portion of the formation, thus indicating a continued uplift of the bottom and subsequent decreasing water depth reaching about 1,500 meters by mid-Pliocene time (Text-fig. 16). Numbers of displaced upper bathyal species increase with time to a high of over 80 percent of total populations in the middle Pliocene corroborating rapid shoaling. More specifically, displaced elements of shelf depth faunas including *Hanzawana nitidula*, a prominent resident of sub-tropical and tropical shelves today (Bandy and Arnal, 1957; Bandy, 1963b), suggest shallowest portions of the Pliocene bank were within wave base. The increasing abundance of rounded and angular pebbles of glaucophane schist within the upper portion of the formation makes this almost a certainty. This unique metamorphic rock occurs in the core of the Palos Verdes uplift (Woodring, Bramlette, and Kew, 1946) and was apparently exposed to wave abrasion by mid-Pliocene time.

SUMMARY

The Malaga Cove Tertiary section represents a series of upper Miocene to middle Pliocene sediments deposited at lower bathyal to middle bathyal depths.

1. Laminated diatomites of the Valmonte Diatomite were deposited on the subsiding floor of a closed basin adjacent to an area of upwelling and high planktonic production. Preservation of laminae occurred due to oxygen values of less than 0.3 ml/l. Depth of the effective sill creating these conditions was at 1,000-1,300 meters as indicated by displaced middle bathyal Foraminifera and depth range of critical oxygen values. A small suite of thin-walled Foraminifera existed intermittently on the basin floor. High radiolarian numbers up to 9,000/gram indicate the floor was 2,000-2,500 meters in depth; increasing spumellarian diameters from 0.20 to 0.40 mm suggest increasing water depth with time.

2. Abrupt transition from continuous laminated diatomites to the radiolarian-rich Malaga Mudstone indicates late Miocene tectonism destroyed the effective sill of the basin. Continued high radiolarian numbers of over 5,000/gram, maximum spumellarian diameters of 0.50 mm, low numbers of diatoms, and increased percentage of terrigenous coarse clay and fine silt suggest the basin floor subsided to 3,000-3,500 meters. Intermittent occurrence of laminated diatomite indicates basin circulation was marginal. Decreasing radiolarian number and decreasing spumellarian diameter indicate shoaling of the basin floor occurred in late Miocene and early Pliocene time.

3. A disconformity brought about by early Pliocene uplift of a local portion of the basin floor separates the radiolarian-rich Malaga Mudstone deposited at over 3,000 meters from foraminiferan-rich glauconitic silts deposited at 2,000-2,500 meters. These tectonics produced an isolated bottom prominence or bank representing the initial phase of the Palos Verdes uplift. Foraminiferal numbers averaging 19,000/gram and high numbers of glauconite pellets suggest characteristically low rates of deposition; established planktonic horizons indicate almost the entire lower Pliocene is represented by 25-30 meters of sediment. Presence of indigenous lower bathyal species together with large percentages of displaced upper and middle bathyal species indicate sediments were deposited on the flank of the bank. Displaced shelf faunas, increasing percentages of upper bathyal species, and rounded pebbles of glaucophane schist indicate the top of the slowly rising bank was within wave base by the mid-Pliocene.

Four vitric tuffs indicate nearby volcanic activity accompanied uplift of the bank during late Miocene and early Pliocene time. More importantly, uplift of the bank occurred at the same time the adjacent Los Angeles Basin was undergoing maximum subsidence.

REPETTO HILLS SECTION

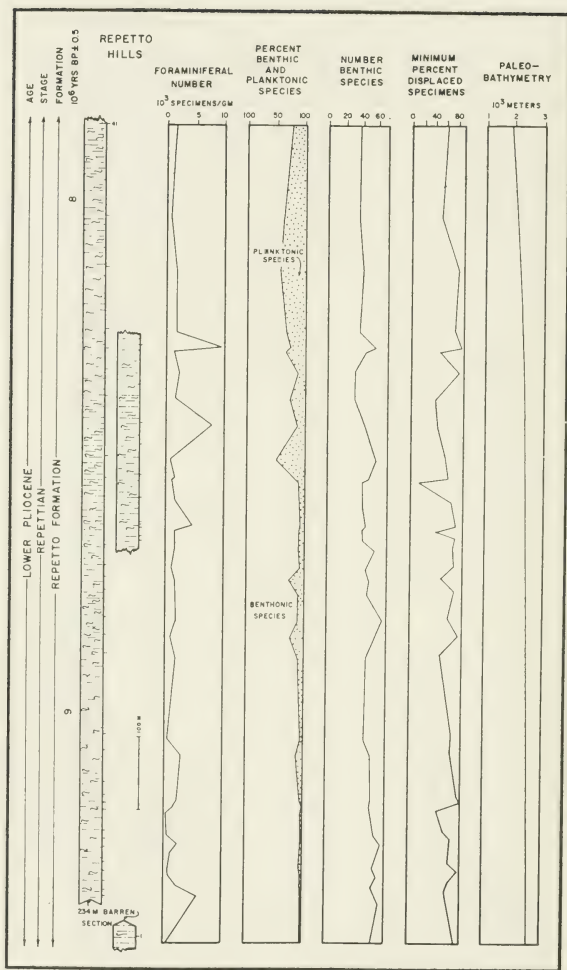
GENERAL STRATIGRAPHY

A comprehensive account of the sediments and depositional patterns within the Repetto Formation (lower Pliocene) of the Los Angeles Basin has been given by Conrey (1958, 1959) and Slosson (1958). The reader is referred to these excellent works for a detailed sedimentologic record and interpretation. Conrey's studies principally illustrate that: (1) the Repetto Formation is characteristically a sandy siltstone (2) sand units were concentrated in the central Los Angeles Basin due to the action of turbidity currents and (3) a predominance of the coarser sediments entered the Los Angeles Basin *via* several submarine canyons and steep slopes in the area adjacent to the Repetto Hills (Text-figs. 1, 2).

The contact between the Repetto Formation and the underlying Puente Formation (Text-fig. 3) is not directly exposed at the base of the Repetto Hills section, however, it is known to be conformable (Troxel, 1954) and gradational (Conrey, 1959) in adjacent areas. As noted previously, the Repetto Hills section (Text-figs. 1, 4) constitutes the type sections of both the Repetto Formation (Reed, 1933) and Repettian microfaunal stage (Natland, 1952; Natland and Rothwell, 1954).

The composite sections sampled along Atlantic Boulevard and Monterey Pass Road (Text-fig. 18) consist of about 1,350 meters of mottled, light grey to brown, sandy, clayey siltstones; percentage of sand increases slightly in the upper portion of the series (Text-fig. 18). Detailed inspection reveals the sediments consist of repeated sequences of graded sands with flow structures and scattered pebble conglomerates containing broken mollusk shells. These coarser units are interbedded with massive micaceous siltstones lacking sedimentary structures or bedding. The sandy, permeable nature of the formation has allowed Foraminifera to be leached from many exposures; a 234 meter sequence within the lower portion of the series was omitted for this reason (Text-figs. 18, 19).

Several discontinuous deep-water sands have been designated as the contact between the Repetto Formation and the overlying Pico Formation for mapping purposes. None of these beds have proven satisfactory;



Text-figure 19.—Foraminiferal number, percentage of planktonic and benthic species, number of benthic species, percentage of displaced specimens, and estimated paleobathymetry of the Repetto Hills section. Note omission of a 234 meter foraminiferan-barren sequence.

consequently variation in benthic foraminiferal faunas continues to serve as a basis for separating the two "formations" (Troxel, 1954; Natland and Rothwell, 1954).

BIOFACIES TRENDS

Constituents of the lower bathyal faunal group (Table 1) are present in every sample from the Repetto Hills section although they exhibit decreasing frequency with time (Text-fig. 18). Two key species of this group, *Melonis pomilioides* and *Pullenia bulloides*, range throughout the sequence in marginal abundances (Text-fig. 18) suggesting sediments were deposited at depths of 2,000-2,600 meters. The absence of *Bulimina rostrata* in the youngest portion of the section suggests shoaling occurred with time. In contrast upper bathyal species occur with increasing frequency upsection also suggesting decreasing water depth.

As might be expected, displaced Foraminifera total 87 percent of some samples and average 67 percent throughout the section (Text-fig. 19). Shelf faunas occur randomly within turbidite sequences and occasionally amount to five percent of the total benthic population (Text-fig. 18). However, it must be noted that the graded intervals (interval Ta of Bouma, 1962) within turbidite sequences were avoided during sampling; thus shelf species would likely occur with much greater frequency on a closer sampling interval (Text-fig. 18). Horizons containing displaced shelf species are accented by the random appearance of the inner shelf species, *Buliminella elegantissima* (Text-fig. 18). It should also be noted that *Hanzawaia nitidula*, a subtropical to tropical shelf-depth species (Bandy, 1963b), is a common constituent of displaced shelf faunas as in the Malaga Cove section (Appendix Table 8).

Gross faunal trends serve to emphasize the displaced nature of the foraminiferal populations. Foraminiferal number averages about 2,100/gram suggesting fairly rapid deposition. These values are in marked contrast to average values of 19,000/gram in slowly deposited early Pliocene bank deposits at Malaga Cove (Text-fig. 17). Planktonic species compose up to 49 percent of some samples and exhibit a general sympathetic increase with increasing percentage of the upper bathyal fauna group with time (Text-fig. 19). This trend suggests many of the planktonic elements were displaced from the shelf edge or upper bathyal areas of high plankton production (Bandy, 1964; Text-figs. 15, 19). Species number averages 35 to 40 in the shallowest portion of the section and increases to an

average of more than 55 in the deepest portions; this variation is the result of increased cumulative mixing of successive faunal groups with depth.

Extremely low radiolarian numbers are in part due to dilution by rapid deposition of coarse sediments and depths shallower than 2,500 meters.

Comparison with the Bunker Hill section.—It is interesting to compare the sequence of benthic faunas within the Repetto Hills section (Text-fig. 18) with those described by Martin (1952) from the Bunker Hill section (Text-figs. 1, 5) 9 km to the west. Martin (1952) subdivided the Bunker Hill section into the "Repetto Formation" and "Pico Formation" on the basis of "diagnostic species" and the presence of two angular unconformities.

One of Martin's (1952) "diagnostic Repetto forms" is *Melonis pompilioides*. However, inspection of Martin's (1952) check list reveals this species is present in both the "Repetto" and "Pico" sediments in the same abundance but with decreasing frequency. *Pullenia bulloides*, another lower bathyal species (Table 1), also occurs sparingly in both "formations." Furthermore, *Uvigerina hispida*, a prominent lower middle bathyal species, occurs with similar frequency in both "formations." It would appear that both of Martin's (1952) units were deposited at 2,000 to 2,500 meters depth. In light of this it is interesting to note that one of Martin's (1952) "diagnostic Repetto forms" is *Cibicides mckennai*, a prominent member of outer shelf faunas today (Bandy and Arnal, 1957); this species also occurs in both "formations" apparently displaced from shelf and upper bathyal depths. It is also revealing that within the group of ten species selected by Martin (1952) as "diagnostic Pico forms" three species are principally upper bathyal forms (*Bolivina spissa*, *Buliminella subfusiformis*, and *Cassidulina translucens*) and two are shelf or shelf-edge forms (*Hanzawaia nitidula* and *Uvigerina juncea*). The fact is that the majority of Martin's (1952) "diagnostic Pico forms" represent displaced species; their increasing abundance in the upper portion of the section simply indicates increased deposition of upper bathyal forms by turbidity currents with time. This same paleoecologic trend is duplicated within the upper portion of the Repetto Hills section where there is a notable increase in abundance of displaced upper bathyal species (Text-fig. 19) with time.

SUMMARY

Gorsline and Emery (1959) noted that submarine fan deposits adjacent to the mouths of submarine canyons in the existing Santa Monica and San Pedro Basins are characterized by sand-shale ratios greater than four to one. Cores taken from these fans and adjacent slopes disclosed characteristic sequences of alternating graded sands and massive clayey silts similar to the sedimentary sequence within the Repetto Hills section (Text-fig. 18). Conrey's (1959) investigation indicates the Repetto Hills section represents sediments deposited adjacent to an early Pliocene submarine canyon and slope complex admitting sediments to the northeast Los Angeles Basin.

The presence of lower bathyal species throughout the 1,350 meter section of graded sands and micaceous clayey siltstones of the Repetto Hills section indicates depth of deposition was about 2,000-2,500 meters (Text-fig. 18). Cumulative percentages of faunal groups indicate that displaced Foraminifera comprise up to 89 percent of the total faunas in turn indicating much downslope displacement of sediment. Rapidly increasing percentages of displaced upper bathyal species and planktonic specimens along with the absence of some lower bathyal indices suggest shoaling of the area was accompanied by more rapid displacement of sediment within upper portions of the section. Irregular foraminiferal numbers and high species numbers also reflect rapid deposition and displaced nature of the benthic faunas. Sedimentary evidence and faunal evidence indicate the Repetto Hills section was deposited at the base of a fairly steep submarine slope and perhaps within a portion of an active submarine fan.

Comparison of sediments and faunas within the Bunker Hill section nine km to the west indicates the sequence there is similar to a portion of the upper Repetto Hills section and that deposition likely took place at the base of a steep slope or fan at lower to middle bathyal depths. Previous separation of two formations within the sequence (Martin, 1952) appears to have been based principally on increased percentages of displaced elements within the upper half of the section. Two closely spaced angular unconformities within the Bunker Hill section probably represent only short intervals of time created by rapid removal of sediment by turbidity currents. Angularity may simply reflect differences in sediment transport and attitude of deposition on the fan somewhat analogous to random deposition on alluvial fans. Equivalence of the Repetto Hills and Bunker Hills sections is further strengthened by planktonic correlations discussed later in the report.

WOODLAND HILLS AND MISSION HILLS SECTIONS

GENERAL STRATIGRAPHY

The Jurassic core of the Santa Monica Mountains forms a highly faulted anticlinal feature upon which Cretaceous through Pleistocene sediments have been deposited during several successive cycles of uplift, erosion, and subsidence (Hoots, 1931; Bailey and Hahns, 1954).

Upper Miocene sediments comprising the Modelo Formation are well exposed on the north flank of the Santa Monica Mountains due to renewed uplift of the anticlinal core during Pliocene and Pleistocene time. In the vicinity of Woodland Hills (Text-figs. 1, 8), the Modelo Formation is about 1,250 meters in thickness and rests unconformably upon middle Miocene Topanga Sandstone (Hoots, 1931).

Sediments of the upper Modelo Formation comprise the lower 640 meters of the Woodland Hills section (Text-figs. 20, 21). A wide range of lithologies characterizes the formation in this area including massive arkosic sands, clayey silts, pink-brown mudstones, diatomaceous shale, and laminated diatomite (Text-fig. 20). The lower 300 meters of the section represents the upper portion of the type section of Kleinpell's (1938) Mohnian Stage (Text-fig. 20). Furthermore, laminated diatomites within the highest portion of the Modelo Formation contain faunas selected by Kleinpell (1938, p. 13-1) as the *Bolivina obliqua* zone of the Delmontian Stage (Text-fig. 3).

The upper 250 meters of the Woodland Hills section are principally silty sands, sandy silts, and massive clayey silts and were assigned to the Repetto Formation on the basis of a lower Pliocene microfauna. These beds were previously included within the Modelo Formation by other workers (Hoots, 1931; Sullwold, 1960) as noted earlier.

The Miocene-Pliocene boundary as defined in this report (10 million years B.P.) is tentatively placed in the uppermost portion of the Modelo Formation on the basis of Yeat's (1965) K-Ar date within the upper Modelo Formation in the Ventura area and corroborating planktonic correlations given later in the report.

The Mission Hills section is exposed in a thrust faulted anticline in the northeast corner of the San Fernando Basin (Text-figs. 1, 9, 22) 18 km northeast of the Woodland Hills section. Both the Modelo and Repetto Formations are exposed in the Mission Hills section, however, folding and faulting allow only abbreviated portions of each unit to be present (Oakeshott, 1958). The Modelo Formation is here composed of a 180

meter thickness of exceptionally uniform laminated diatomites containing upper Mohnian Stage microfaunas. A major fault separates this unit from an overlying 250 meter thickness of the Repetto Formation composed of fine sands, massive sandy siltstone, and several conglomerates. The Repetto Formation is thrust over a younger series of arkosic sands assigned to the middle Pliocene Pico Formation by Oakeshott (1958).

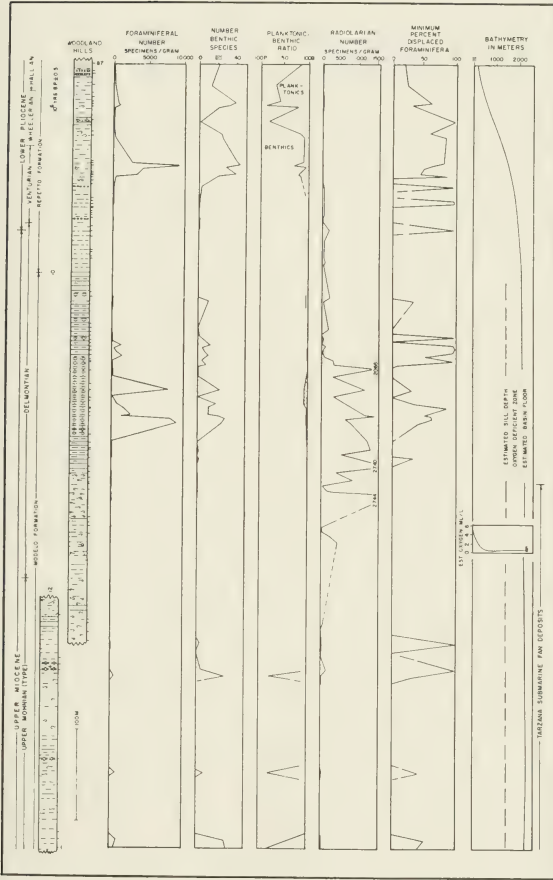
LITHOFACIES AND BIOFACIES TRENDS

The Woodland Hills section (Text-fig. 20) can be conveniently subdivided into four paleoecologic facies based upon distinct variations of sediments and microfaunas: (1) Tarzana Submarine Fan facies (2) Diatom-Radiolaria facies (3) basin slope facies, and (4) shelf facies.

Tarzana submarine fan facies.—Detailed studies by Sullwold (1960) indicate a major portion of the late Miocene Modelo Formation was deposited by gravity transport on a broad submarine fan. The lower 400 meters of the Woodland Hills section includes a number of massive sand units (Text-fig. 20) representing material deposited during the final phases of Sullwold's (1960) Tarzana Fan.

Individual sands within the fan sequence are up to four meters in thickness, however, they are laterally discontinuous because of their mode of origin. Successive sequences of turbidite sands separated by thin shale horizons form sand "units" up to 30 meters in thickness. These sands exhibit the multitude of sedimentologic features associated with turbidites such as load casts, graded intervals, plume structures, carbonaceous trash, and more; all are described and illustrated in detail by Sullwold (1960). The silty and clayey sands are interbedded with indigenous deep water sediments, principally light brown to pink-brown mudstones, micaceous silty clays, and clayey silts. Many of these fine-grained units also exhibit flow structures. A few random horizons of diatomaceous shale are also present (Text-fig. 20).

Foraminifera and Radiolaria are usually rare or absent from the deep water sand units due to: (1) dilution by instantaneously deposited coarse sediments and (2) solution of tests within the permeable sands. Nevertheless, scattered faunas occur within some of the indigenous bathyal sediments, principally within laminated diatomaceous shales (Text-figs. 20, 21). Foraminiferal number within the fan deposits ranges from 535/gram to 971/gram, however, if abundance in all sedimentary units were considered, the average value would be less than 10/gram.



Text-figure 21.—Foraminiferal number, number of benthic species, percentages of planktonic and benthic species, radiolarian number, percentage of displaced Foraminifera, and estimated paleobathymetry within the Woodland Hills section.

Benthic faunas of the fan sediments are characterized by (1) significant percentages of species characteristic of low oxygen conditions (2) high cumulative percentages of displaced species from inner shelf to lower middle bathyal depths and (3) abnormally high percentages of planktonic species (Text-figs. 20, 21). Species from the impoverished group (Table 1) are assumed to represent the indigenous fauna; these include *Bolivina benedictensis*, an index to the upper Mohnian Stage (Kleinpell, 1938; Pierce, 1956), along with *Bolivina pseudospissa*, *Bolivina seminuda*, and variants. *Suggrunda eckisi*, a key index to low oxygen conditions is also present (Appendix Table 11). Presence of laminated diatomites and of an impoverished faunal group indicates that the Tarzana Submarine Fan was deposited within a closed basin and that oxygen values were less than 0.3 ml/l below sill depth. Intermittent preservation of laminae apparently occurred between periods of instantaneous deposition of coarse sediments. However, high percentages of species displaced from above sill depth indicate that downslope transport was continuous (Text-fig. 20).

Deepest displaced elements include transitional species from middle bathyal depths including *Urigerina hispidocostata* and *Valvulineria araucana malagaensis*. These species and preserved laminae suggest the sill depth was about 1,300-1,400 meters. High percentages of planktonic species are also characteristic of displaced faunas as noted earlier (Bandy, 1964a).

Depth of the basin floor is difficult to estimate due to dilution of radiolarian faunas. Radiolarian numbers vary from 0 to 143/gram. Maximum spumellarian diameter reaches 0.25 mm, approximately half the diameter of species from the deepest portion of the Malaga Cove section (Appendix Table 8), and suggests that the basin floor was less than 2,000 meters in depth. Comparison with modern basins (Emery, 1960, p. 109) indicates the basin floor was at least 500 meters below sill depth or about 2,000 meters. Laminated diatomites composing the lower portion of the Mission Hills section (Text-fig. 22) also contain a benthic fauna characteristic of low oxygen conditions along with abundances of *Bolivina benedictensis* and *Discorbinella ralmonicensis* placing it within the upper Mohnian Stage of Kleinpell (Text-fig. 22; Appendix Table 12). Planktonic correlations given later in the report suggest this section was deposited slightly prior to deposition of the lowest portion of the Woodland Hills section. Consequently, it is of interest to compare the two sections. The Mission Hills diatomites contain a suite of benthic species almost identical

to those found in the Tarzana Fan deposits. As in the Woodland Hills section, displaced shelf through upper bathyal forms compose over 80 percent of some samples; furthermore, middle bathyal species and the lower limit of critical oxygen values within the water column (Calvert, 1964) suggest the sill depth was at 1,300-1,400 meters. Although radiolarian number reaches 5,734/gram, maximum spumellarian diameter averages about 0.25 mm suggesting the basin floor was 2,000 meters or less in depth. Thus quiet, continuous, and undisturbed deposition of diatomaceous laminae took place in the northeastern portion of the San Fernando Basin at the same time great quantities of coarse sediments were being deposited on the floor of the stagnant basin 18 km to the southwest. Faunal inferences indicate depth of the basin floor and oxygen values were essentially identical in the two areas.

Diatom-Radiolaria facies.—The massive turbidite sands of the Tarzana Fan give way upsection to an overlying 225 meter thick unit composed of pink-brown mudstones, micaceous clayey siltstones, diatomaceous shales, and laminated diatomites. The mudstones, siltstones, and diatomaceous shales bracket a 100 meter thick unit of continuous laminated diatomites (Text-fig. 20) similar to those described from the Mission Hills section (Text-fig. 22). Graded sands occur randomly throughout this sequence but are commonly less than four cm in thickness.

The transition from the massive sands to the predominantly finer grained sediments represents the apparent cessation of vigorous deposition on the Tarzana Fan. One possible explanation for this cessation involves tectonic adjustment of basin margins, alteration of the configuration of the parent submarine canyon, and slight subsidence of the basin floor. Radiolarian number increases to 2,744/gram within the youngest fan deposits and the immediately overlying mudstones (Text-fig. 21). Radiolarian number remains between 500 and 1,000/gram in the diatomaceous sequence but in overlying sediments begins to decrease to between 251 and 17/gram. Maximum spumellarian diameter increases to 0.37 mm in the mudstones immediately overlying the massive sands (Appendix Table 11). Simultaneous occurrence of peak radiolarian abundance and maximum spumellarian diameter suggests the basin floor subsided to its deepest point concurrently with cessation of active deposition on the fan. The increase in spumellarian diameter indicates the basin floor may have subsided to 2,100 to 2,200 meters.

the effective sill depth of the basin may have been elevated somewhat in concert with the period of increased subsidence. Species from group 6 (Table 1), the impoverished basin fauna, predominate within this unit. *Bolivina rankini* and *Bolivina seminuda* are present in abundance. Deepest displaced elements from above sill depth remain middle bathyal species (Text-fig. 20). Displaced faunas average over 40 percent and comprise up to 100 percent of some populations within the diatomaceous laminae; displaced shelf and upper bathyal species including *Buliminella curta* and *Uvigerina peregrina* constitute 50 percent of some samples (Text-fig. 20).

It is interesting to note that *Bolivina obliqua*, a key species to a portion of Klempell's (1938) Delmontian Stage, is limited to the laminated diatomite sequence suggesting its occurrence was restricted to low oxygen settings. There are in fact a number of "species" common to diatomaceous sequences such as *Bolivina granti* and *Bolivina parva* which may simply represent ecophenotypic variants of a single species, *Bolivina hughesi*, produced under marginal conditions. In the same respect *Bolivina bootsi* and *Bolivina goudkoffi*, forms with half-clear half-opaque chambers, appear to represent variants of *Bolivina seminuda*, a species common to low oxygen environments today (Harman, 1964).

Basin slope facies.—The 100 meter unit of laminated diatomites is immediately overlain by an alternating series of mudstones and interbedded diatomaceous shales indicating sill configuration was altered again at about the Miocene-Pliocene boundary (Text-fig. 20). The sedimentary and faunal sequence in the uppermost 250 meters of the section suggests that rapid shoaling of the basin occurred during the early Pliocene. Important faunal trends indicating decreasing water depth include: (1) a decrease in radiolarian number from over 300/gram to less than 1/gram (2) a decrease in maximum spumellarian diameter from an average exceeding 0.25 mm to an average of less than 0.15 mm and (3) an increase in foraminiferal number from less than 1/gram to a high of 9,450/gram at middle bathyal depths (Text-fig. 21). Displaced Foraminifera dominate in lower slope deposits (Text-fig. 21) suggesting alteration of the basin sill was accompanied by increased downslope displacement of sediment. Sediments composing this facies show a transition from mudstones to clayey silts to massive silts with interbedded turbidite sands.

Lower middle bathyal species constitute the indigenous fauna in the lower portion of the basin slope sequence, however, displaced upper bathyal and shelf assemblages total 50 to 80 percent of many samples.

Water depth decreased rapidly from about 1,800 to 150 meters at the shelf edge. Increasing percentages of planktonic species occur upsection and reach a maximum in upper bathyal and shelf edge deposits duplicating trends in modern environments (Text-fig. 21). The lower Pliocene portion of the Mission Hills section also contains lower middle bathyal species although the total populations are dominated by displaced upper bathyal species (Text-fig. 22). However, sediments contrast sharply with those deposited at the same time and at similar depths near Woodland Hills (Text-fig. 20). The Mission Hills sequence is dominated by coarse sediments with interbedded shales and silts whereas the equivalent Woodland Hills sequence is composed chiefly of mudstones to sandy siltstones. The lower Pliocene sequence exposed within Mission Hills may represent a portion of a submarine fan deposit in light of the high percentage of coarse sediments and the modern relationships defined by Gorsline and Emery (1959).

Shelf facies.—The uppermost 60 meters of the Woodland Hills section exhibits an increasing percentage of fine sand; the final few meters are composed of silty sandstone.

Variation in gross faunal parameters document the change from upper bathyal to shelf conditions: (1) percentage of displaced faunas decreases from over 50 percent to less than 25 percent (2) percentage of planktonic species drops sharply to 20 percent and (3) foraminiferal number decreases from over 600/gram at the shelf edge to less than 10/gram (Text-fig. 21). Moreover, species from the inner and outer shelf groups (Table 1) comprise 90 percent of the benthic populations.

It is important to note that *Hanzawaia nitidula* totals 33 percent of the inner shelf assemblage within the shallowest portion of the facies (Appendix Table 11). This species also amounts to 20 percent of displaced shelf groups in the upper and middle bathyal portions of the section. *Hanzawaia nitidula* is an important constituent of shelf faunas off Baja California, in the Gulf of California, and off Central America today (Bandy and Arnal, 1957; Bandy, 1961). Furthermore, abundance increases with higher water temperature or with decreasing latitude. For example, Bandy (1963b) noted that *Hanzawaia nitidula* amounts to ten percent of inner littoral faunas within the Gulf of California but is absent from equivalent environments off southern California; Walton's (1955) studies showed *H. nitidula* constitutes up to three percent of the shelf fauna off northern Baja California; and finally Bandy and Arnal (1957)

noted that *H. nitidula* amounts to 40 percent of the inner shelf populations off Central America. Considering the above trend and the high percentage of *Hanzawaia nitidula* in the Pliocene shelf facies of Woodland Hills (Appendix Table 11) it seems reasonable to assume water temperatures over the shelf during the early Pliocene were subtropical, perhaps reaching 25°C. Planktonic trends also indicate temperatures were warmer during the early Pliocene as compared with modern temperature profiles at the same latitude. This species also occurred within displaced shelf assemblages in the lower Pliocene Repetto Hills section and Malaga Cove section as noted earlier.

The shelf sediments also contain two vitric tuffs (Text-fig. 20) indicating nearby volcanic activity during the early Pliocene. Finally, abundant mollusk shells occur within the stratigraphically highest beds characteristic of shelf depth deposits; shark teeth and whale vertebrae are also present.

SUMMARY

Massive sands and interbedded fine-grained deposits within the upper Modelo Formation have been shown to represent an upper Miocene submarine fan deposit termed the Tarzana Fan (Sullwold, 1960). Foraminifera and radiolarians are rare within the deep-water sands but occur infrequently within the interbedded diatomaceous shales. Foraminiferal number varies from 535/gram to 971/gram within the indigenous deep-water sediments. Intermittent beds of laminated diatomite and indigenous restricted basin faunas indicate that the fan was deposited below sill depth of a closed basin characterized by oxygen values of less than 0.3 ml/l. Species displaced from shelf and upper and middle bathyal depths comprise 30 to 100 percent of the benthic faunas. Planktonic species comprise up to 80 percent of some populations; many of these specimens were likely displaced from upper bathyal areas. Critical oxygen minimum depths (Calvert, 1964) and deepest displaced elements suggest the sill depth was 1,300-1,400 meters. Radiolarian number is low due to dilution of faunas by turbidites. Maximum spumellarian diameters of less than 0.25 mm and comparison with modern silled basins (Emery, 1960, p. 109) suggest the basin floor was about 2,000 meters in depth. Planktonic correlations between the Woodland Hills section and the Mission Hills section indicate quiet deposition of laminated diatomite took place in the northeast portion of the stagnant basin at the same time vigorous deposition of coarse sediments occurred on the Tarzana Fan.

The Tarzana Fan deposits give way to a sequence of mudstones and a 100 meter thick unit of laminated diatomite. Cessation of fan deposition may have occurred due to tectonic alteration of basin margins. An increase in radiolarian number to over 2,000/gram, an increase in spumellarian diameter to 0.37 mm, and continuous preservation of laminae suggest the basin floor subsided several hundred meters whereas sill depth remained at about 1,300 meters. Foraminiferal number is irregular within the laminated diatomites and members of the restricted basin fauna predominate within benthic populations. *Bolivina rankini*, a thin-walled species, occurs in prolific numbers.

Structural activity again altered basin configuration at the Miocene-Pliocene boundary. Due to subsequent increased circulation deposition of laminated diatomites was intermittent and rapidly gave way to lower middle bathyal deposits of clayey silts and sandy silts. Rapid shoaling of the basin during the early Pliocene is indicated by an abrupt decrease in radiolarian abundance and subsequent increase in foraminiferal number to over 9,000/gram. Lower middle bathyal faunas appear initially along with high percentages of displaced upper bathyal and shelf species. Planktonic species increase in percentage and exceed 50 percent of the total populations in upper bathyal deposits. An abrupt decrease in percentages of planktonic species and displaced benthic species characterizes shelf depth deposits along with increasing percentages of indigenous inner and outer shelf faunal elements. High percentages of the subtropical outer shelf species *Hanzawaia nitidula* suggest water temperature was perhaps 25°C over the early Pliocene shelf.

PLANKTONIC FACIES VARIATION

GENERAL

Three recent papers have clearly delineated some of the critical problems encountered in use of planktonic Foraminifera for correlation (Wade, 1964; Jenkins, 1965; Parker, 1965). Parker (1965) rightly pointed out that stratigraphers in their current enthusiasm over plankters have tended to overlook the implications of modern distributions.

Because planktonic assemblages are deposited ubiquitously over the bottom regardless of bathymetric irregularities and varied provincial benthic populations they presumably offer a superior means of establishing "time" horizons (Bandy, 1964b; Parker, 1965) within bathyal marginal deposits and deep-sea areas. The fact is, however, that the ecology of planktonic

organisms rivals the ecologic complexity exhibited by benthic groups. As with studies of benthic Foraminifera, only the superficial controls of distribution of planktonic species are currently known. Studies of living planktonic Foraminifera in the North Pacific (Bradshaw, 1959; Smith, 1963, 1964) and elsewhere (Bé, 1959, 1960; Beliaeva, 1962, 1965; Cifelli, 1965) have shown these animals to be generally distributed in accord with temperature and current patterns within a given ocean basin. Moreover, a specific faunal group characterizes each major water-mass province (Bradshaw, 1959). Studies of other holoplanktonic groups, euphausiid crustaceans in particular (Brinton, 1962; Johnson and Brinton, 1963), have shown them to be similarly distributed. The distribution of planktonic tests on the ocean floors generally reflects their living patterns within a given water-mass (Phleger, Parker, and Pierson, 1953; Parker, 1958; Waller and Polski, 1959; Boltovsky, 1959, 1962; Bandy, 1961; Parker, 1962; Kustanowich, 1963; and others).

Superimposed upon the ecologic distribution of planktonic faunas at any moment is their evolutionary sequence with resultant appearance and extinction of different species with time. Concentrated study of middle Tertiary planktonic populations has revealed that a consistent sequence of species has appeared and disappeared with time within tropical latitudes (Bolli, 1957; Blow, 1959; Bermudez, 1961; Eames, Banner and Blow, 1962; and others). This general sequence or portions thereof have been readily recognized in tropical and warm temperate deposits of the Pacific Basin (Hornibrook, 1958; Jenkins, 1960; Chang, 1962; Asano, 1962; Sawai, 1962; Belford, 1962; Saito, 1963; Bandy, 1963d; Wade, 1964; McTavish, 1966). Bandy (1964b) compiled a state-of-the-art summary concerning the Tertiary planktonic sequence in warm temperate and tropical areas and recommended boundary criteria.

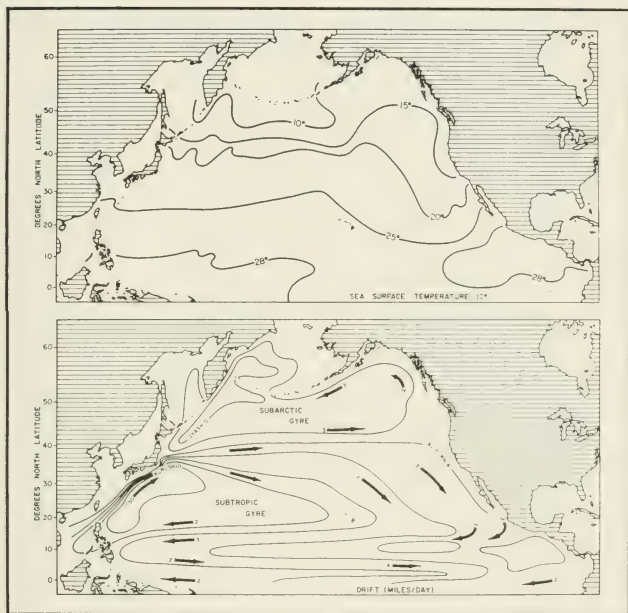
As noted by Bandy (1964b) recognition of the warm water planktonic zones becomes increasingly difficult proceeding poleward from the equator due to temperature requirements of critical species. Moreover, initial appearance of critical morphotypes is not always synchronous in high and low latitudes (Bandy, 1966). The Miocene-Pliocene boundary offers an excellent case-in-point. Bandy (1964b) and others (Bolli, 1964; Huang, 1964; Jenkins, 1964; Riedel and Funnel, 1964) utilized the initial appearance of "*Sphaeroidinella debiscens*," *Globorotalia inflata*, and *Globorotalia truncatulinoides* as marking the base of the Pliocene in warm and warm-temperate deposits of the Pacific region. Unfortunately, these

species do not appear in cold-temperate and subarctic deposits due to their living habits (Bradshaw, 1959; Parker, 1962). Thus the Miocene-Pliocene boundary as defined by the presence of these species cannot be extended to all areas.

The southern California region occupies a critical transition zone between areas dominated by subarctic and warm-temperate planktonic assemblages today (Bradshaw, 1959) and presumably did so in the past. Thus it can be expected that variations in warm temperature and current patterns with time have allowed oscillating dominance of cool or warm-temperate faunas in the region. This is in marked contrast to the persistence of tropical faunas in equatorial areas and the monotonous occurrence of boreal faunas at high latitudes during the middle and late Tertiary. Consequently, variations in planktonic facies in the upper Miocene through Pleistocene sediments of southern California were interpreted in terms of deviations from the present day "standard" species distribution in the marginal eastern North Pacific at latitude $33^{\circ} 48'$ north. Thus interpretations of the late Tertiary faunas in this region must be preceded by a review of modern planktonic distributions in the marginal North Pacific with emphasis on irregularities in species distribution produced by an asymmetric current system.

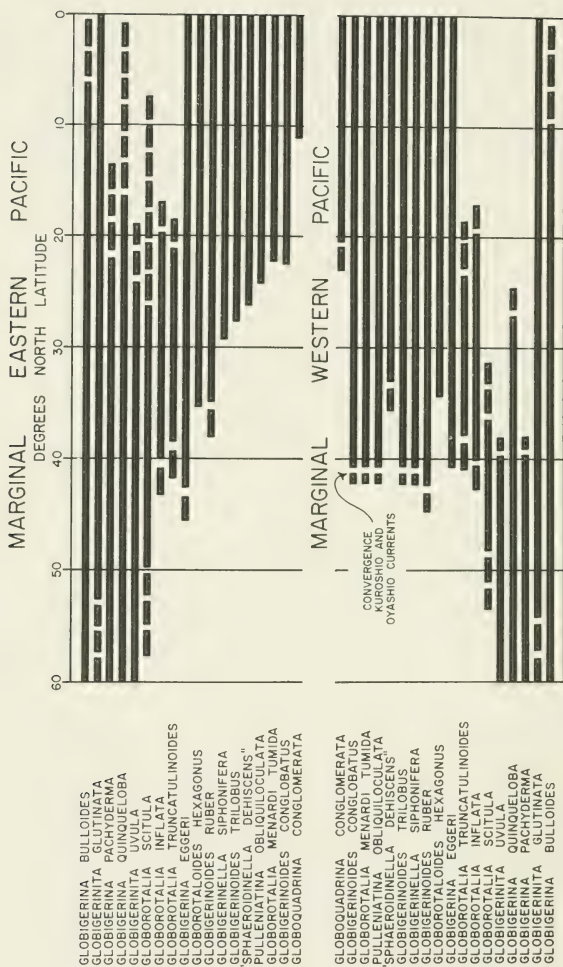
EFFECT OF AN ASYMMETRIC CURRENT SYSTEM

Both the Atlantic and Pacific oceans possess well-developed eastern boundary currents with source areas in high latitudes due to the physics of wind driven ocean circulation (Munk, 1950; Malkus, 1963; Fofonoff, 1963; Wooster and Reid, 1963). Generalized patterns of isotherms, surface geostrophic circulation, and drift in the North Pacific (Text-fig. 23) clearly illustrate the asymmetric character of water movement in this portion of the Pacific Basin. The relatively slow equatorward California Current delivers cool water south along the eastern margin to about latitude 25° north where mixing occurs; in the marginal western Pacific the swift Kuroshio Current carries warm water north to about latitude 41° where convergence with the Oyashio Current occurs (Text-fig. 23). The effect of this system is strikingly illustrated by noting occurrence of similar species at the leading edges of the eastern and western North Pacific (Text-fig. 24). Not surprisingly, there are discrepancies of over 20° in latitude in the distribution of some species at the eastern and western margins (Text-fig. 24). For example, the boreal species *Globigerina pachyderma*

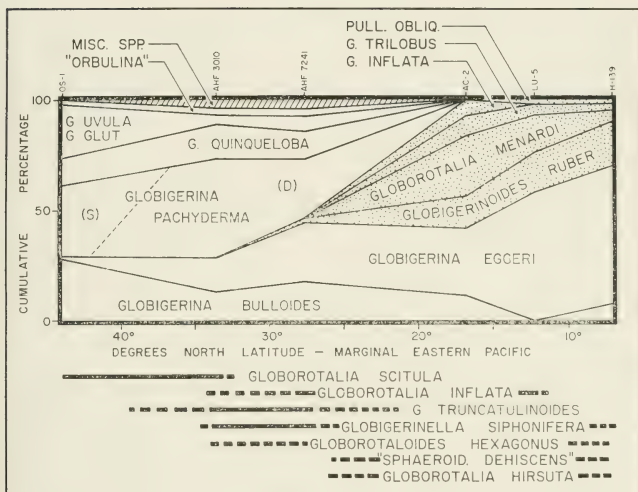


Text-figure 23.—Generalized surface temperature (C°) and surface circulation (miles/day) in the North Pacific. Adapted from Bradshaw (1959), Reid (1961) and Tully (1965).

occurs south to about latitude 36° in the western Pacific whereas its distribution extends south to at least latitude 15° in the eastern Pacific. Due to the high velocity Kuroshio Current a number of tropical species including *Globigerinoides conglobatus*, *Globorotalia menardi tumida*, and *Pulleniatina obliquiloculata* occur north to latitude 43° north in the western Pacific whereas the same species are restricted to the area south of latitude 25° north in the marginal eastern Pacific (Text-fig. 24). This pattern of distribution is particularly pertinent to analysis of Miocene through Pleistocene planktonic faunas in the marginal deposits of North America and western Asia and any resultant correlations.



Text-figure 24.— Distribution of selected common planktonic Foraminifera in the marginal eastern and western North Pacific. Plotted from data in Bandy and Arnel (1957), Waller and Polski (1959), Bradshaw (1959), Smith (1963) and Recent samples analyzed during this study.



Text-figure 25.—Cumulative distribution of planktonic Foraminifera along a north-south traverse in the marginal eastern North Pacific. Samples ac-2, lu-5, and h-139 plotted from data in Bandy and Arnal (1957). D and S represent dextral and sinistral coiling provinces of *Globigerina pachyderma*.

EFFECT OF THE CALIFORNIA CURRENT ON MIOCENE TO RECENT PLANKTONIC ASSEMBLAGES

An analysis of species distribution along a north-south traverse in a portion of the marginal eastern North Pacific illustrates the effect of the California Current on planktonic populations today (Text-fig. 25). Important trends along this generalized profile include: (1) the dominance of a boreal planktonic fauna characterized by *Globigerina bulloides* and *Globigerina pachyderma* south to about latitude 25° or the zone of mixing (Text-fig. 23) (2) sinistral coiling preference of *Globigerina pachyderma* north of latitude 45° (3) increasing percentages of *Globigerina eggeri* and variants equatorward to a point where it comprises up to 50 percent of subtropical and tropical faunas south of latitude 25° (4) significant percentages of *Globorotalia inflata* at the leading edge of the subtropical faunal group between latitudes 25° and 15° and (5) the restriction of *Globo-*

rotalia truncatulinoides to the transition zone between latitudes 40° to 20° (Text-fig. 25).

Investigations of Miocene to Pleistocene planktonic faunas from the Pacific coast of North America are few to date (Galloway and Wissler, 1927; Bandy, 1960a; Ingle, 1962, 1963a; Bandy and Kolpack, 1963; Lipps, 1964; Parker, 1964; Fowler, 1965), however, all illustrate that the equatorward California Current has actively maintained a dominantly boreal planktonic fauna south to at least latitude 30° since the middle Miocene. Two analyses serve to illustrate the dominance of subarctic and cool-temperate species in Miocene through Pleistocene deep-water sequences in this area.

Quantitative analysis of limited planktonic assemblages from middle Tertiary sediments of the Tecolote Tunnel (Bandy and Kolpack, 1963) illustrates that middle Miocene faunas are dominated by *Globigerina concinna* and that this species exhibits a decrease in size with time (Text-fig. 26). A transition occurs in latest middle Miocene sediments where *Globigerina bulloides* and variants become dominant members of the planktonic fauna (Text-fig. 26). Dominance of *Globigerina concinna* was also noted in middle Miocene sediments of the Washington coast (Fowler, 1965).

It has been suggested by some that *Globigerina concinna* represents a recurrent morphotype of *Globigerina bulloides* (Wade, 1964) whereas others consider it the ancestor of *Globigerina quinqueloba* (Fowler, 1965). Whichever the case, its abundance in Miocene sediments deposited beneath cool eastern boundary currents in both the Pacific (Ingle, 1962; Bandy and Kolpack, 1963; Fowler, 1965) and Atlantic (Drooger and Batjes, 1959) suggests it had its origin within a boreal region. Furthermore, its common appearance in Miocene deposits of southern Australia (Wade, 1964) indicates it has a bipolar distribution similar to the abundant occurrences of *Globigerina bulloides* and *Globigerina pachyderma* today (Bradshaw, 1959; Parker, 1962). In fact, its presence in southwest Australia gives evidence of the persistence of the unnamed, little known, and anomalous (Wooster and Reid, 1963) eastern boundary current of the Indian Ocean.

Despite the dominance of boreal planktonic species in the lower middle Miocene of the marginal eastern North Pacific, tropical elements do appear occasionally (Bandy, 1963a; Bandy and Kolpack, 1963;

TABLE 2.—RELATIVE ABUNDANCE OF FORAMINIFERA IN TURBIDITE SEQUENCE, PICO FORMATION, BALCOM CANYON SECTION

SAMPLE NO.	Ta	Te
PLANKTONIC SPECIES		
GLIOBERGERINA BULLOIDES BULLOIDES	73	
GLIOBERGERINA PACHTERDERMA	9	
GLIOBERGERINA QUINQUELOBA	9	
GLIOBERGERINA UYULA	9	
RENTHIC SPECIES		
AMMONIA BECCARI TERPIDA	1	
BOLIVINA ARGENTEA	1	
BOLIVINA INTERJUNCTA	X	
BOLIVINA PACIFICA	X	
BOLIVINA SONATA	X	
BOLIVINA SUBADYENA SULPHUREMBIS	3	
BOLIVINA VAUGHANI	9	
BOLIVINA PACODA	X	
BOLIVINELLA ELEGANTISSIMA	9	
CASSIDULINA CALIFORNICA	19	
CASSIDULINA DELICATA	1	
CASSIDULINA SURGULOSA QUADRATA	X	
CASSIDULINA SURGULOSA SURGULOSA	4	
CASSIDULINA TORTUOSA	3	
CYPRIDITES LUTATUS	3	
EXTINGUISHING TRANSLUCENS	13	
EXTINGUISHING BRADYANA	1	
EXTINGUISHING LUCIDA	1	
GLIOBERGERINA PACIFICA	2	
GLIOBERGERINA CONFINATA	3	
HANJALIA NITIDULA	2	
HANJALIA NITIDULA	6	
LACUNA BULGATA	1	
LYGIDIA INORNATA	3	
LYGIDIA LOCULINA COSTATA	3	
LYGIDIA LOCULINA LAMARKIANA	8	
NOTICINELLA LOMAXENSIS	X	
TRICLINELLA INORNATA LONGICOSTATA	1	
TRICLINELLA INORNATA	2	
TRICLINELLA PACIFICA	4	
UVCERINA HISPIDA	2	
UVCERINA HISPIDICOSTATA	16	
UVCERINA HOOTSI HOOTSI	5	
UVCERINA HOOTSI MODELOFFENSIS	2	
UVCERINA KERNENSIS	14	
UVCERINA PEREGRINA	4	54
PERCENT RENTHIC SPECIES		
PERCENT HYALINE	76	100
PERCENT ARENACEOUS	12	
PERCENT PORCELLANEUS	12	
MINIMUM PERCENT DISPLACED SPECIES	95	70
PERCENT PLANKTONIC SPECIES	11	
TOTALS		
PERCENT FORAMINIFERA	71	96
PERCENT OSTRACODS	8	
PERCENT RADIOLARIANS	21	2
SPECIMENS COUNTED	156	174

SPECIES ABUNDANCE GIVEN AS PERCENT OF TOTAL

RENTHIC OR PLANKTONIC FAUNA

X - LESS THAN 1 PERCENT

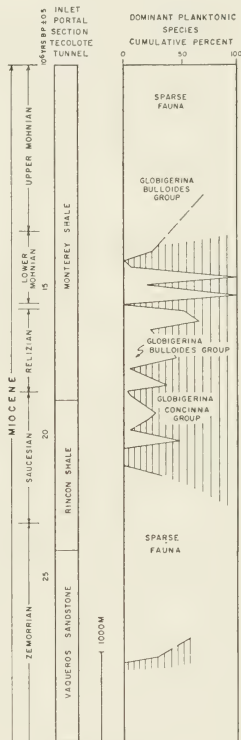
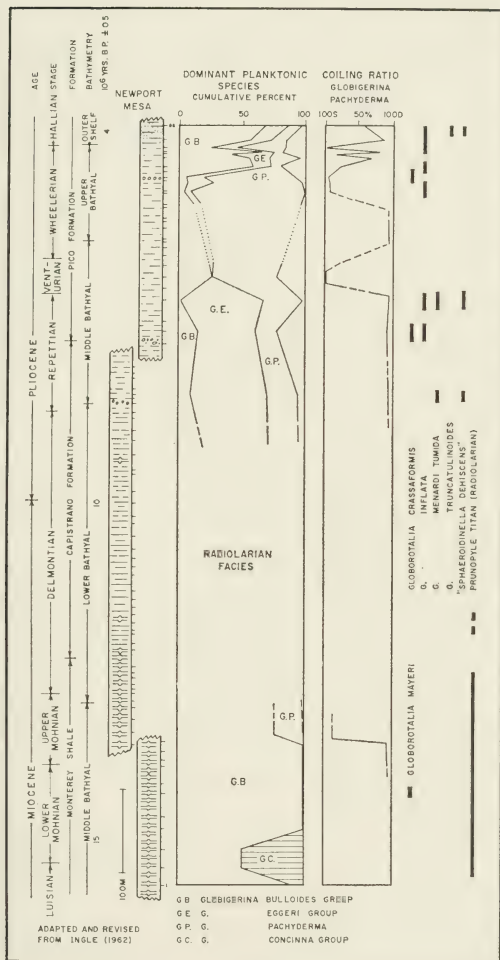
ADAPTED FROM DATA BY
BANDY AND KOLPACK (1963)
EVERNDEN ET AL. (1964)

Table 2.—Relative abundances of Foraminifera and other microfossils within a turbidite sequence in the Pliocene Pico Formation, Balcom Canyon. Sample Ta represents the graded interval and sample Te the pelitic intervals of Bouma (1962).

Text-figure 26.—Cumulative frequency of common planktonic Foraminifera in the inlet portal section of the Tecolote Tunnel. Plotted from data in Bandy and Kolpack (1963); radiometric dates extrapolated from Evernden, Savage, Curtis, and James (1964).

Parker, 1964; Lipps, 1964; Fowler, 1965) as in other temperate areas (Wade, 1964; Reed, 1965). That they occur with greater frequency in lower and middle Miocene sediments of temperate areas is likely due to the steep temperature gradient postulated for the middle Miocene in the Pacific area (Emiliani, 1961; Dorman, 1966) and corroborated by the rapid equatorward regression of Panamanian province benthic faunas during the middle Miocene (Kleinpell, 1938; discussion in this paper). Perhaps the most striking evidence of this rapid mid-Miocene adjustment is the abrupt influx of a boreal planktonic fauna in the upper middle Miocene sediments of northern Japan (Saito, 1963). The fauna is dominated by *Globigerina bulloides* and occurs in strata immediately overlying deposits containing a well-developed warm water *Globorotalia fohsi fohsi* fauna (Saito, 1963). This variation suggests the Kuroshio-Oyashio convergence was shifted south in the mid-Miocene close to its present position (Text-fig. 23).

A quantitative investigation of common planktonic species from upper middle Miocene to upper Pliocene sediments in strata exposed at Newport Mesa (Ingle, 1962, 1963a; Text-fig. 27) provides further evidence of the continued control of the California Current system during the late Tertiary of southern California. This analysis illustrates that (1) *Globigerina concinna* rapidly decreases in abundance in the upper Miocene and is absent from Pliocene sediments (2) *Globigerina pachyderma* makes its initial appearance in the upper Miocene (lower Mohnian Stage) increases in abundance and exhibits sinistral coiling during the latest Miocene (3) *Globigerina bulloides* increases in abundance in the late Miocene faunas and remains a prominent member of all later faunas (4) an abundant zone of *Globigerina eggeri* characterizes the early Pliocene along with initial appearances of *Globorotalia crassaformis*, *Globorotalia menardi tumida* and "*Sphaeroidinella debiscens*," (5) *Globigerina pachyderma* exhibits predominantly sinistral coiling in the middle Pliocene and alternating dextral-sinistral coiling in the late Pliocene along with sympathetic increases in abundance and (6) *Globorotalia truncatulinoides* appears initially in the late Pliocene (fig. 27). Examination of large planktonic assemblages from Luisian Stage and Mohnian Stage sediments at Newport Mesa by Lipps (1964) revealed the occasional occurrence of several tropical elements including *Globigerinoides trilobus trilobus*, *Globoquadrina conglomera*, and *Globorotalia mayeri*.



Text-figure 27.—Cumulative frequency of common planktonic Foraminifera, coiling ratio of *Globigerina puchadama*, and stratigraphic ranges of important minor species in the Newport Mesa section (Text-fig. 1); adapted and revised from Ingle (1962). Alignment of the radiometric scale is estimated from correlations of planktonic zones and available radiometric dates in nearby areas together with radiometric scales presented by Evernden, Savage, Curtis, and James (1964), and Bard (1966a).

Thus the planktonic trends within the Tecolote Tunnel and Newport Mesa sections clearly indicate that cool-temperate faunas have prevailed in southern California areas at least since the late middle Miocene with the exception of the early Pliocene. Furthermore, the gross planktonic trends within these two sections serve as a framework against which detailed analysis of variations across the Miocene-Pliocene boundary can be placed.

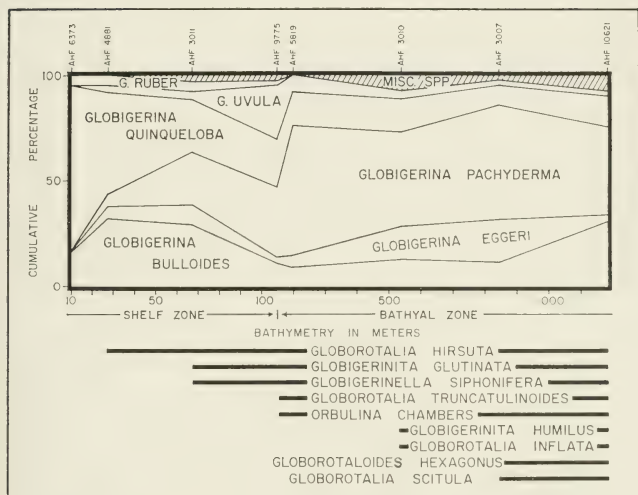
PLANKTONIC FACIES VARIATION WITH DEPTH

Modern and fossil paralic and inner shelf deposits are characterized by extremely low numbers of planktonic Foraminifera as discussed and illustrated (Text-fig. 23) earlier. Due to the abrupt increase in planktonic number at the shelf edge the number of planktonic species also shows a marked increase at the same point. It has been speculated that the depth distribution of planktonic Foraminifera in water covering the continental shelves is a response to the relatively wide variations in salinity, temperature, and turbulence characterizing this environment; further study is needed to clarify ecologic controls. However, some planktonic species appear to be restricted to specific depths even in the open ocean; for instance closing-net studies by Bradshaw (1959) and Casey (1963) suggest *Globigerina pachyderma* and *Globorotalia scitula* consistently occur deeper than 150 meters. Furthermore, Bé and Lott (1964) and Bé (1965) have convincingly demonstrated that some planktonic morphotypes are developed almost exclusively at great depths.

Possible planktonic faunal changes with depth are of particular importance to studies of planktonic assemblages within the Tertiary marine sequences so vigorously examined along the continental margins of the world. These sections invariably represent areas of relatively rapid deposition, great tectonic adjustment, and the random intercalation of bathyal and shelf depth deposits. It is, therefore, pertinent to document any differences in composition of planktonic assemblages within modern shelf and bathyal deposits.

Cumulative distribution of planktonic species along an east-west traverse off southern California (Text-fig. 28; Appendix Table 6) clearly illustrates that there are distinct differences between the planktonic assemblages over shelf and bathyal areas. Nine species were noted in sediments shallower than 150 meters whereas 15 species⁶ were found in sedi-

⁶ Including "Orbulina" chambers.



Text-figure 28.—Cumulative frequency of planktonic Foraminifera within a series of progressively deeper samples off southern California (Appendix Table 6).

ments at the shelf edge and deeper (Text-fig. 28). *Globigerina quinqueloba*, *Globigerina bulloides*, and *Globigerinoides ruber* form an exclusive inner shelf fauna. Number of planktonic tests per gram of sediment on the inner shelf is generally less than one whereas planktonic number increases to over 100 at the shelf edge (Bandy, Ingle, and Resig, 1964c). Consequently, the relatively abrupt increase of *Globigerina pachyderma* at the shelf edge assumes added significance and is in accord with Bradshaw's (1959) and Casey's (1963) data.

It is particularly interesting to compare the modern horizontal distribution above (Text-fig. 28) with a vertical fossil sequence "traversing" shelf to bathyal depths with time. Planktonic faunas within shelf and bathyal deposits of the Pliocene Pico Formation in Balcom Canyon (Ventura County) provide an excellent parallel to the modern traverse (Text-fig. 29).

Benthic Foraminifera within the Balcom Canyon section clearly indicate that progressive shoaling occurred during the late Pliocene. The

shelf-depth sediments of this section contain a fauna characterized by *Bulimina marginata denudata*, *Nonionella basispinata*, and *Nonionella miocenica stella* typical of nearby modern shelf areas (Bandy, Ingle, and Resig, 1964c). The shelf edge is marked by *Uvigerina juncea* and *Angulogerina angulosa*: upper bathyal and upper middle bathyal faunas successively appear downsection (Text-fig. 29).

The trends in cumulative frequency of planktonic species in the Pliocene section (Text-fig. 29) are almost identical to those exhibited in the modern profile. Eight planktonic species characterize the shelf-depth deposits whereas 13 species⁷ were found in the bathyal deposits. Moreover, *Globigerina pachyderma* increased abruptly in abundance at the shelf edge (Text-fig. 29) as it does today (Text-fig. 28) and *G. quinqueloba* forms the dominant planktonic species in shelf-depth deposits. Absence of significant percentages of *Globigerinoides ruber* is likely the result of cooler surface temperatures during this portion of the Pliocene as indicated by the fluctuations in coiling preference of *Globigerina pachyderma*.

It seems apparent from the two examples given above that the total planktonic fauna of a given region is not represented within inner shelf deposits, a conclusion suggested previously by Bandy (1964) and Parker (1965). Moreover, certain planktonic species are relatively more abundant over the shelf areas than in deeper water. These aspects together with characteristically low numbers of planktonic tests necessitate caution in the use of planktonic assemblages from paralic and shelf depth deposits for correlation purposes. Consequently, the present investigation was restricted to sediments deposited at bathyal depths.

LATE MIOCENE AND PLIOCENE PLANKTONIC ZONATION IN SOUTHERN CALIFORNIA

LATE MIOCENE TRENDS

Planktonic assemblages within the Woodland Hills and Mission Hills section (Text-figs. 22, 30) together with information obtained from the Newport Mesa section (Text-fig. 27) illustrate that the late Miocene in southern California was punctuated by a period of cool-temperate to subarctic surface temperature. The occasional presence of subtropical planktonic elements allows recognition of portions of the "*Globorotalia mayeri* zone" and "*Sphaeroidinellopsis seminulina* zone" defined in upper Miocene

⁷ Including "Orbulina" chambers.

sediments of warm water regions (Bolli, 1959; Blow, 1959; Takayanagi and Saito, 1962; Saito, 1963; Bandy, 1963c, 1964b; and others).

The generalized profile along the marginal eastern North Pacific (Text-fig. 25) indicates predominantly sinistrally coiling specimens of *Globigerina pachyderma* are restricted to areas north of latitude 45° today. The abundance and sinistral nature of this species in polar areas has been well documented (Green, 1960; Bandy, 1960a). Predominantly dextrally coiling specimens of *G. pachyderma* were initially found in sediments containing a lower Mohnian benthic fauna at Newport Mesa (fig. 27). *Globigerina pachyderma* exhibits a rapid increase in relative abundance within overlying upper Mohnian Stage sediments and displays an abrupt change from predominantly dextral coiling to sinistral coiling (Text-fig. 27). These trends are interpreted as a response to rapidly decreasing surface temperature in light of modern distributions (Text-fig. 25).

The California Current has its source at high latitudes (Text-fig. 23); thus it is reasonable to assume that cooler surface temperature in the southern California region during the past was a reflection of a physical change in the arctic area. The most plausible cause of a critical decrease in surface temperature at high latitudes is the onset of glaciation and formation of sea ice. Rutherford, Craddock, and Bastien (1965) have presented radiometric evidence suggesting the onset of glaciation in Antarctica did indeed occur during the late Miocene. Based on our knowledge of Pleistocene events it seems reasonable to assume that a period of refrigeration may also have been simultaneously initiated in the Arctic. A switch from dextral to sinistral coiling exhibited by *Globigerina pachyderma* in upper Miocene sediments deposited beneath the paleo-California Current offers indirect evidence of this event.

It is also important to note that *Globigerina concinna* occurs with diminishing frequency immediately prior to the inferred decrease in water temperature (Text-fig. 27). This trend suggests that the extinction of *G. concinna* during the late Miocene may have been brought about by rapidly decreasing surface temperatures in the boreal faunal provinces of both hemispheres.

Although late Miocene planktonic assemblages in southern California are dominated by cool water species (Text-figs. 26, 27), several significant occurrences of warm temperate and tropical species allow correlations to be made with the well-known tropical planktonic biozones. *Globorotalia*

mayeri appears sparingly within the lower portion of lower Mohnian Stage sediments at Newport Mesa (Text-fig. 27) but is absent from younger horizons (Text-fig. 27). Assuming this occurrence represents its upper limit, the oldest portion of lower Mohnian Stage sediments at Newport Mesa (Text-fig. 27) is equivalent to the upper portion of the "*Globorotalia mayeri* zone" of the tropics (Blow, 1959; Bandy, 1964b). Portions of this zone have been recognized in other temperate areas of the Pacific Basin (Wade, 1964).

The upper limits of the upper Miocene zone of sinistral coiling *Globigerina pachyderma* cannot be established within the Newport Mesa section due to subsidence and introduction of a lower bathyal radiolarian facies (Text-fig. 27). Fortunately planktonic assemblages in the middle bathyal sediments of the Mission Hills and Woodland Hills sections allow further definition of this biofacies.

Predominantly sinistrally coiling specimens of *Globigerina pachyderma* comprise up to 60 percent of the planktonic assemblages in the laminated diatomites of the Mission Hills section (Text-fig. 22). As noted previously this series contains a typical upper Mohnian Stage benthic assemblage. Tropical and warm temperate species are again present as rare constituents and include *Globigerina druryi decoraperta*, *Globigerinoides trilobus immaturus*, and *Sphaeroidinellopsis seminulina* (Text-fig. 22). It is also pertinent to note that *Globorotalia menardi tumida*^s has been reported from upper Mohnian Stage sediments in the nearby Santa Barbara area (Bandy and Kolpack, 1963; Plate 41, fig. 4, this paper); this is the earliest reported occurrence of this species from the California Miocene.

Turning to the Woodland Hills section (Text-fig. 30) the oldest planktonic assemblages present are characterized by moderate percentages of sinistrally coiling specimens of *Globigerina pachyderma* and high percentages of *G. bulloides*. Significant tropical elements are restricted to the lowest two samples and include *Globigerinoides ruber*, *Globigerinoides trilobus immaturus*, *Globigerinoides trilobus trilobus*, and typically developed *Sphaeroidinellopsis subdehiscens* (Text-fig. 30). Warm temperate species present include *Globigerina druryi decoraperta*, sinistral forms of *Globigerina eggeri* and *Globorotaloides hexagonus*. *Sphaeroidinellopsis seminulina* and *S. subdehiscens* are absent from overlying beds. Consequently, the upper Mohnian Stage sediments in the Mission Hills section

^s The specimen found lacks a crystalline crust and would therefore be classified as *Globorotalia menardi menardi* by some investigators (Plate 41, fig. 4).

and the basal sediments of the Woodland Hills section (Text-figs. 22, 30) are equivalent in part to the "*Sphaeroidinellopsis seminulina* zone" of tropical regions. These species may be absent from younger strata due to low surface temperature. In fact it is only reasonable to assume tropical species such as *S. seminulina* resided for a longer period in equatorial regions than in cool-temperate areas creating a time-lag in their upper limits in low and high latitudes. In any event the occurrence of *S. subdehiscens* in upper Mohnian Stage sediments marks the last appearance in southern California of a species assignable to one of the "standard" tropical Miocene planktonic zones as they are presently understood.

Globigerina druryi decoraperta appears to be most common in upper Miocene warm temperate deposits (Takayanagi and Saito, 1962) although Parker (1964) reported it from lower Pliocene sediments in the experimental MOHOLE cores. *Globigerina eggeri*, another predominantly warm temperate species (Text-fig. 25), makes its initial appearance in the upper Mohnian Stage sediments of the Mission Hills and Woodland Hills sections (Text-figs. 22, 30; Appendix Table 11). Surprisingly this species is predominantly sinistrally coiling in these early occurrences; this is in marked contrast to the abundant dextral specimens dominating in Pliocene to Recent warm temperate and tropical faunas. This trend is especially noteworthy in light of Bolli's (1964) recent finding of a similar sinistral horizon of *G. eggeri* in the latest Miocene⁹ of Venezuela. However, *G. eggeri* is exclusively dextral in Miocene sediments of the western Pacific (Bandy, 1963c; Bolli, 1964) restricting the usefulness of the sinistral horizon.

Although correlations with the tropical sequence are interesting and necessary, the trends exhibited by the dominant boreal planktonic species in southern California are far more significant on a local level. Thus it is important to note that *Globigerina pachyderma* continues to exhibit sinistral coiling in the uppermost portion of the Mohnian sediments at Woodland Hills along with continued dominance of *Globigerina bulloides* (Text-fig. 30). However, faunal gaps created by turbidite sequences mask planktonic trends in the uppermost portion of the Tarzana Fan deposits (Text-fig. 30). This faunal gap is also maintained at this point due to subsidence and the appearance of a lower middle bathyal radiolarian facies lacking Foraminifera. Similar radiolarian facies result in similar planktonic

⁹ Bolli (1964) placed the Miocene-Pliocene boundary at the initial appearance of "*Sphaeroidinella dehiscens*" after Bandy (1964b).

faunal gaps in the Newport Mesa and Malaga Cove sections (Text-figs. 27, 27).

Globigerina pachyderma exhibits an abrupt switch from sinistral to dextral coiling in the basal portion of the laminated diatomite facies; these beds contain a Delmontian Stage benthic fauna as noted earlier (Text-fig. 20). An isolated sample containing a Delmontian Stage fauna from the basal Malaga Mudstone (Appendix Table 8) in the Los Angeles Basin contains a sinistral population of *G. pachyderma* suggesting the base of this stage is slightly older in this area than at Woodland Hills.

Presumably the switch to dextral coiling displayed by *G. pachyderma* during the late Miocene (Text-fig. 30) was a response to increasing surface temperature. Again one can appeal to a waning of late Miocene polar refrigeration as the mechanism responsible for increased temperatures within the California Current system. A conservative view involves the continuous presence of sea ice at the poles during the late Miocene rather than extensive glaciation and the recession of these packs during the latest Miocene. Whatever the cause, dextral populations of *G. pachyderma* in upper Miocene sediments of southern California (Text-fig. 30) mark the onset of a period of steadily increasing surface temperature which reached a climax during the early Pliocene.

Increasing water temperature inferred by late Miocene planktonic trends (Text-fig. 30) is corroborated by analyses of upper Miocene molluscan assemblages from several adjacent areas (Woodring and Bramlette, 1950; Winterer and Durham, 1962; Stanton, 1966). In fact Panamanian taxa are present in upper Miocene shallow water assemblages as far north as central California (Durham and Addicott, 1965). Interestingly, the warm water mollusks within these megafaunas have caused them to be classified as lower Pliocene whereas micropaleontologists have assigned the simultaneously occurring benthic microfaunas to the upper Miocene Delmontian Stage. Regardless of the criterion utilized to define the Miocene-Pliocene boundary, planktonic Foraminifera and shallow water mollusks both indicate surface temperature increased between 12 and 10 million years before the present (B.P.) in southern California following an earlier cool temperate and subarctic phase.

Planktonic faunas within the lower Pliocene bathyal facies of the Woodland Hills section (Text-fig. 30) continue to reflect increasing surface temperatures. Although *Globigerina bulloides* and dextral populations of *G. pachyderma* predominate, *G. eggeri* increases in abundance com-

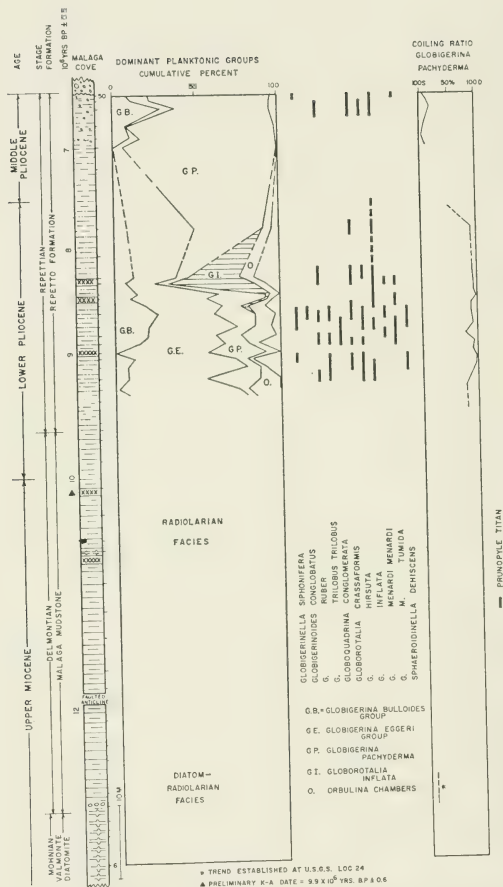
prising up to 25 percent of individual faunas (Text-fig. 30). *Globorotalia crassaformis* and *G. inflata* also appear initially within these beds. The first appearance of *G. crassaformis* has been considered indicative of the latest Miocene and early Pliocene in other temperate (Jenkins, 1964) and tropical areas (Bandy, 1963, 1964b)¹⁰ of the Pacific.

Tropical and warm temperate species present in the lower Pliocene beds at Woodland Hills (Text-fig. 30) include *Globigerinoides conglobatus*, *G. trilobus trilobus*, and *Globorotaloides hexagonus*. Rapid shoaling and appearance of a shelf facies in the uppermost portion of this section precludes the presence of a complete planktonic fauna. *Globigerina quinqueloba* increases in abundance with the shelf facies (Text-fig. 30) duplicating trends observed in modern and fossil shelf environments (Text-figs. 28, 29). As noted earlier, benthic species within this lower Pliocene shelf facies are indicative of subtropical conditions corroborating planktonic trends.

Range of Prunopyle titan.—Lower bathyal deposits rich in radiolarians, devoid of Foraminifera, and in general analogous to deposits in deep basins in the Gulf of California (Table 3) span the Miocene-Pliocene boundary in portions of the Los Angeles and Ventura basins. Deposits of this nature occur in the Newport Mesa, Malaga Cove, and Woodland Hills sections (Text-figs. 17, 27, 30) and were discussed earlier. The absence of significant numbers of planktonic Foraminifera within these facies creates gaps in planktonic zonation. However, this problem is overcome in part by the use of the radiolarian *Prunopyle titan*. This massive and easily recognized spumellarian (Plate 13, fig. 8) was originally described from Mohnian Stage sediments in the Newport Mesa section (Campbell and Clark, 1944). Analysis of radiolarian faunas throughout the Newport Mesa section (Ingle, 1962) reveals that this species appears initially within Luisian Stage diatomites deposited approximately 16 million years B.P. Upper limit of the species occurs within lower bathyal "Delmontian Stage"¹¹ sediments deposited about 11 million years B.P. (Text-fig. 27) or just prior to the Miocene-Pliocene boundary as defined in this report. This species exhibits a similar range in middle and lower bathyal deposits in the Malaga Cove and Woodland Hills sections (Text-fig. 30, 31).

¹⁰ *Globorotalia crassaformis* was recorded as *G. puncticulata* by Bandy (1963c).

¹¹ These sediments are assigned to the "Delmontian Stage" simply on the basis of stratigraphic position as Foraminifera are absent from the radiolarian facies (Text-fig. 27; Ingle, 1962, 1963b).



Text-figure 31. - Cumulative frequency of common planktonic species, coiling ratio of *Globigerina pachyderma*, absolute ranges of selected planktonic species, and absolute range of *Prunopyle titan* within the Malaga Cove section.

The upper limit of *Prunopyle titan* in deep-water facies thus constitutes an important local planktonic datum in southern California and may prove to be significant in other areas of the Pacific Basin. The upper limit of *Prunopyle titan* proved to be a particularly useful planktonic "time" horizon in the correlation of bathyal Miocene sequences at Newport Mesa (Text-fig. 14) and Dana Point 32 km to the south (Ingle, 1962, 1963b). Furthermore, this species has been recognized in cores taken in the antarctic region (Hays, 1965) where it likely marks Miocene deposits (Bandy, 1966b) or reworked occurrences. The usefulness of this form for long range correlations is somewhat enhanced by its probable restriction in the Miocene water column to depths greater than 1,500-2,000 meters. Planktonic forms living at such depths are in some cases little affected by the comparatively abrupt variations in temperature common to shallower horizons and consequently tend to be ubiquitous in their distribution. Orlov (1959, p. 627) has termed such radiolarians panbathypelagic.

EARLY PLIOCENE TRENDS

General planktonic trends in the Newport Mesa section (Text-fig. 27) indicate that *Globigerina eggeri* increased in abundance during the early Pliocene continuing the trend initially observed in the Mission Hills section (Text-fig. 22). Analogy with modern planktonic facies in the eastern Pacific (Text-fig. 25) suggests this trend was the result of a continued increase in surface temperature. Although *Globigerina eggeri* is living off the southern California coast (Text-fig. 25) it becomes a dominant faunal constituent south of latitude 28° in subtropical and tropical waters (Text-fig. 25).

More detailed analyses of early Pliocene planktonic assemblages within the Repetto Hills, Bunker Hill, and Malaga Cove sections (Text-figs. 31, 32, 33) allow refinement of the general trends previously established in the Newport Mesa section (Ingle, 1962) and clearly document the subtropical nature of the fauna. Inspection of planktonic trends within these sections (Text-figs. 31, 32, 33) reveals several common characteristics: (1) dextral coiling specimens of *Globigerina eggeri* comprise well over 80 percent of many faunas and are generally present in numbers far greater than occur at this latitude today (2) *Globorotalia inflata* abruptly increases in abundance for a short period in the upper portion of each sequence and commonly composes over 50 percent of specimens within this zone and (3) "*Sphaeroidinella debiscens*" and other tropical and

subtropical species including *Globigerinella siphonifera*, *Globigerinoides conglobatus*, *G. ruber*, *G. trilobus sacculifer*, *G. trilobus trilobus*, *Globoquadrina conglomerata*, *Globorotalia hirsuta*, *G. menardi menardi*, *G. menardi tumida*, *Globorotaloides hexagonus*, and *Pulleniatina obliquiloculata* occur as rare to common faunal constituents throughout each sequence (Text-figs. 31, 32, 33).

The abundance of *Globigerina bulloides* and dextral forms of *G. pachyderma* generally decrease upward in the lower Pliocene whereas *G. eggeri* increases in abundance reaching a peak in the middle lower Pliocene. Populations of *G. eggeri* are dominated by forms with a low or flat spiral side and four to five appressed chambers in the last whorl. Specimens possessing a high spire and five to six robust chambers in the last whorl, as shown in the type of this species, amount to less than ten percent of any given population of *G. eggeri*.

The subtropical character of these early Pliocene assemblages is striking and clearly indicates that surface temperatures were significantly higher during this period than occur at the same latitude today. The fact that *Globorotalia menardi tumida* composes up to six percent¹² of some samples, together with the persistent occurrence of "*Sphaeroidinella debiscens*," suggest surface temperature may have exceeded 25°C during the early Pliocene.

The initial appearance of "*Sphaeroidinella debiscens*" within the lower Pliocene sediments of southern California (Text-figs. 27, 31, 32, 33) is consistent with Bandy's (1964b) definition of lower Pliocene sediments in tropical and warm temperate areas. However, it again seems reasonable to assume that there may have been a time-lag between the initial appearance of this morphotype in tropical areas and its appearance in temperate areas. The likelihood of such a discrepancy is especially strong in light of the planktonic evidence of a slow expansion of warm isotherms into the southern California region during the latest Miocene and earliest Pliocene (Text-fig. 30). The gradual rise in temperature during this period may have allowed a staggered and controlled appearance of planktonic elements common to warmer seas. For instance, *Globorotalia inflata*, a warm temperature species (Bradshaw, 1959; Parker, 1962), occurs initially in the earliest Pliocene sediments of the Woodland Hills section apparently arriving in the area ahead of "*Sphaeroidinella subdebiscens*." It is also pertinent to

¹² Percentage of tropical species would be several times higher if "*Orbulina*" morphotypes were omitted from calculations (Appendix Tables 8, 9, 10).

note that *Globorotalia crassaformis*, a form closely related to *G. inflata* (Ujiié, 1963), also appears prior to the arrival of "*Sphaeroidinella debiscens*" (Text-fig. 30). Furthermore, *Globorotalia crassaformis* and *G. inflata* have both been recorded from numerous upper Miocene deposits in the Philippines (Bandy, 1963c) and Japan (Saito, 1963). These occurrences suggest that this species complex originated in the warm western Pacific during the late Miocene but did not arrive in southern California until the early Pliocene (Text-fig. 30).

The delay in arrival of "*Sphaeroidinella debiscens*" morphotypes in southern California apparently occurred in response to critically low surface temperature whereas the delay in arrival of *Globorotalia inflata* from the western Pacific was due primarily to time necessary for migration as this species is tolerant of moderate temperatures. Moreover, recent evidence indicates "*Sphaeroidinella debiscens*" represents a morphotypic derivative of several tropical planktonic species which add a thick cortex at depth (Bé, 1965; Bandy, Ingle and Frerichs, 1965). The principal species exhibiting this random, gerontic, metamorphic character is *Globigerinoides trilobus*, one of the most common members of equatorial planktonic populations today and in the past. Modern planktonic distributions indicate "*Sphaeroidinella debiscens*" develops principally in tropical regions whereas *Globigerinoides trilobus* ranges into warm temperate regions (Bradshaw, 1959; Bé, 1965). Consequently, it seems only logical that this morphotypic development should initially appear in tropical regions supporting large populations of the parent species. As surface temperatures reached a maximum during the early Pliocene of southern California, "*Sphaeroidinella debiscens*" appeared in conjunction with increasing frequency of *Globigerinoides trilobus*. However, *G. trilobus* is found randomly in upper Miocene samples throughout the Woodland Hills section whereas *Sphaeroidinellopsis subdebiscens*, also a possible morphotypic derivative of *G. trilobus* (Bé, 1965), occurs only in the lower portion of the section (Text-fig. 30).

Sphaeroidinellopsis seminulina, *S. subdebiscens*, and "*Sphaeroidinella debiscens*" appear successively at the "Miocene-Pliocene" boundary in tropical regions of the Pacific (Bandy, 1963c, 1963d, 1964b). In view of this tropical succession one can only assume that the same "boundary" is represented in southern California within the time-gap between the uppermost occurrence of *Sphaeroidinellopsis subdebiscens* in upper Miocene Mohnian Stage sediments (Text-fig. 30) and the initial appearance of

"*Sphaeroidinella debiscens*" much later in the lower Pliocene (Text-fig. 31). Thus it seems almost a certainty that the appearance of "*Sphaeroidinella debiscens*" in southern California is not isochronous with its initial appearance in tropical regions. The magnitude of this discrepancy remains to be established. The occurrence of *Sphaeriodinellopsis seminulina* in lower Pliocene sediments of the experimental MOHOLE cores (Parker, 1965) 1,120 km to the south suggests this time-lag may be small. On the other hand *S. seminulina* is not present in lower Pliocene planktonic assemblages in the Repetto Hills section which in all other respects are identical to those in the experimental MOHOLE cores.

The climax of the early Pliocene expansion of warm isotherms into the southern California area seems to be marked by the irregular appearance of *Globigerinoides trilobus sacculifer*, *Globoquadrina conglomerata*, and *Pulleniatina obliquiloculata* immediately prior to the *Globorotalia inflata* zone (Text-figs. 31, 32).

The consistently appearing zone of abundant *Globorotalia inflata* in the upper lower Pliocene (Text-figs. 31, 32, 33¹³) constitutes an important local "time" horizon. Again turning to the modern profile off North America (Text-fig. 25), analogy suggests the high percentages of *Globorotalia inflata* in the lower Pliocene sequence correspond to the faunal zone at the leading edge of the tropical planktonic group (Text-fig. 25). The position of this zone today corresponds roughly with the zone of mixing between the cool California Current and warm equatorial water. It is also interesting to note a similar fauna dominated by *Globorotalia inflata* and marginal occurrences of tropical species characterizes the subtropical convergence in the South Pacific (Kustanowich, 1963). Thus the occurrence of this peculiar fauna during the early Pliocene sequence of southern California implies the zone of mixing at the distal end of the California Current had migrated approximately seven to ten degrees north of its present position. In turn this implies a critical physical change occurred in the source area of the California Current during the early Pliocene allowing a poleward transgression of warm isotherms. Following the concept of late Miocene polar refrigeration presented earlier, one must assume the early Pliocene warm phase in southern California reflects a period of maximum temperature in between periods of polar refrigeration. Not only would such a condition allow expansion of warm isotherms but equatorward drift of the eastern boundary currents would be much slower than today or during periods of maximum polar refrigeration.

¹³ See Text-fig. 33 on page 308.

The unique *Globorotalia inflata* zone also allows relatively precise correlation between the Repetto Hills, Bunker Hill, and Malaga Cove sections (Text-figs. 31, 32, 33). The marked presence of this zone in the Bunker Hill section (Text-fig. 32) corroborates the earlier conclusion based on ecologic implications of benthic species that this section is equivalent to a portion of the upper Repetto Hills section (Text-fig. 32). The appearance of this zone at Malaga Cove (Text-fig. 31) serves to emphasize the telescoped nature of this section due to the low rate of sedimentation. The planktonic sequence represented within 1,350 meters of sediment deposited at the base of a lower Pliocene basin slope (Text-fig. 32) is duplicated in only 25 to 30 meters of glauconitic sediments deposited on the flank of a seamount or bank (Text-fig. 31).

MIDDLE PLIOCENE TRENDS

Continued abundance of *Globigerina eggeri*, dextrally coiling *Globigerina pachyderma*, and occasional occurrence of tropical species indicate that the temperature continued warm for some time after the early Pliocene maximum (Text-figs. 27, 31). However, planktonic trends in the Newport Mesa and the Malaga Cove sections indicate an abrupt decrease in surface temperature occurred during the mid-Pliocene of southern California (Text-figs. 27, 31).

Globigerina pachyderma increases in abundance immediately above the *Globorotalia inflata* zone in the Malaga Cove section (Text-fig. 31) heralding the onset of decreasing water temperatures. Finally *Globigerina pachyderma* exhibits an abrupt switch from dextral to sinistral coiling climaxing this trend (Text-fig. 31; Bandy, 1960). Simultaneously *Globigerina eggeri* decreases in abundance and amounts to less than ten percent of faunas within this zone; conversely *G. pachyderma* amounts to over 75 percent of most samples. This same trend is evident in the mid-Pliocene portion of the Newport Mesa section (Text-fig. 27). Thus assemblages typical of Bradshaw's (1959) subarctic fauna indicate surface temperatures may have decreased to 10°C during the mid-Pliocene of this area.

Bandy (1960a) initially recognized the mid-Pliocene sinistral zone of *Globigerina pachyderma* in the central Los Angeles Basin; it has subsequently been identified in the Newport Mesa section (Text-fig. 27; Ingle, 1962) and in numerous oil wells throughout the area (Bandy, 1966c). Consequently, the upper or lower boundaries of this zone con-

stitute local isochronous surfaces and serve as excellent criteria in recognition of mid-Pliocene sediments. Estimated alignment of the radiometric scale suggests this zone of subarctic temperature existed between 7 and 6.5 million years B.P.

The relatively localized nature of such coiling shifts in response to oceanographic changes in specific regions limits the usefulness of this particular boundary criterion to the regime of the California Current system. Presumably, the introduction of a subarctic planktonic fauna in southern California during the mid-Pliocene was again a response to a critical decrease in surface temperatures in the high latitude source area. Moreover, a period of decreased surface temperature must have caused a contraction of large-scale interactions over the North Pacific, an increase in vertical circulation, and a general increase in speed of the eastern boundary current driving warm isotherms far to the south of their present positions.

In this regard it is interesting to note that there is significant faunal evidence that California-province mollusks entered the Gulf of California during such periods of decreased surface temperature in the eastern Pacific (R. H. Parker, 1964). Moreover, a temperate planktonic foraminiferal population characterized by high percentages of dextral *Globigerina pachyderma* is concentrated in the upper reaches of the gulf today (Bandy, 1961) whereas the mouth of the gulf is within a subtropical faunal province. This pattern suggests the dextral populations of *G. pachyderma* invaded the gulf during a period when cool temperate isotherms were located south of the tip of the Baja California Peninsula. These invasions of cool water taxa into the gulf resulting in trapped faunas are presumed to have occurred in the Pleistocene (R. H. Parker, 1964). However, the evidence indicating subarctic temperatures in the mid-Pliocene of southern California (Text-figs. 27, 31) suggests these migrations began much earlier.

Although subtropical and tropical species occur sparingly within the earliest portion of the mid-Pliocene cool period (Text-fig. 31) rapidly decreasing temperature eliminates them completely by the end of this phase (Fig-fig. 27).

LATE PLIOCENE TRENDS

General planktonic trends within upper Pliocene sediments are adequately illustrated by assemblages within the Newport Mesa, and Balcom Canyon sections (Text-figs. 27, 29) and in the San Diego Formation (Text-fig. 11; Table 4).

TABLE 4 - RELATIVE ABUNDANCE OF PLANKTONIC FORAMINIFERA, SAN DIEGO FORMATION, PACIFIC BEACH SECTION

SAMPLE NO.	1	2
<u>PLANKTONIC SPECIES</u>		
GLOBIGERINA BULLOIDES BULLOIDES	19	45
GLONIGERINA BULLOIDES QUADRILATERA		2
GLOBIGERINA EGGERI EGGERI	3	X
GLOBIGERINA EGGERI--VARIANTS	9	3
GLOBIGERINA PACHYDERMA	33	43
PERCENT SINISTRAL SPECIMENS	3	83
GLOBIGERINA QUINQUELOBA	7	3
GLOBIGERINELLA SIPHONIFERA	X	X
GLOBIGERINITA GLUTINATA	X	
GLOBIGERINOIDES CONGLOBATUS	X	X
GLOBIGERINOIDES RUBER	15	2
GLOBIGERINOIDES TRILOBUS TRILOBUS	2	
GLOBOQUADRINA CONGLOMERATA	X	
GLOBOROTALIA CRASSAFORMIS	1	X
GLOBOROTALIA INFLATA	1	
GLOBOROTALIA MENARDI TUMIDA	X	X
GLOBOROTALIA HIRSU'TA	X	
"ORBULINA" CHAMBERS	17	1
SPECIMENS COUNTED	209	289

Table 4.—Relative abundance of planktonic Foraminifera from the San Diego Formation, Pacific Beach, California. Abundances are given as percent of the total planktonic population. See Text-figure 11 for location of samples.

Globigerina pachyderma remained the predominant species during the late Pliocene (Text-fig. 27) however, it again changed coiling direction from sinistral to dextral during the initial phase of the late Pliocene (Text-figs. 27, 29; Bandy, 1960a). Warm temperate species including *Globorotalia crassaformis* and *G. inflata* again appear in low abundances after their absence during the climax of the mid-Pliocene cool phase (Text-fig. 27). The predominance of dextrally coiling specimens of *Globigerina pachyderma* and *G. bulloides* together with low numbers of *G. eggeri* and other warm temperate species indicates surface temperatures increased to about 16° to 18°C, approximately equivalent to values immediately offshore today.

Three significant planktonic events occurred during the latter portion of the late Pliocene: (1) abrupt changes in coiling direction of *Globigerina pachyderma* took place (2) *Globorotalia truncatulinoides* made its initial appearance in southern California and (3) a significant short term increase in surface temperature allowed the entrance of a distinctly subtropical fauna immediately prior to the initial phases of the Pleistocene subarctic period.

Planktonic faunas within bathyal sediments of the upper Pliocene portion of the Pico Formation at Balcom Canyon clearly demonstrate the alternating coiling habit of *Globigerina pachyderma* (Text-fig. 29). These alternations are interpreted as a response to the early phases of "Pleistocene" glaciation. Assuming the sinistral populations of *G. pachyderma* are indicative of the 10° to 11° isotherm suggests that alternations in coiling record the random incursion of subarctic surface temperatures into the southern California area about four to five million years B.P. (Text-fig. 29). Earlier periods of subarctic temperature during the late Miocene (Text-fig. 27) and mid-Pliocene (Text-figs. 27, 31) suggests that refrigeration of the poles had taken place prior to the appearance of low surface temperatures during the late Pliocene. Thus the staccato appearance of cool and temperate isotherms was probably due to the waxing of polar ice prior to the onset of the more intense periods of glaciation initiated about three million years B.P. Moreover, the planktonic faunas present in the earlier portion of the upper Pliocene are essentially identical to those living at the same latitude today, during a period of waning but effective polar refrigeration.

The appearance of *Globorotalia truncatulinoides* in the upper Pliocene sediments of the Newport Mesa (Text-fig. 27) and Balcom Canyon sections (Text-fig. 29) is of critical importance. This diagnostic species is a common constituent of lower Pliocene planktonic faunas throughout the tropical and warm temperate Pacific (Bandy, 1963c; Huang, 1964; Aoki, 1963) indicating a possible time-lag of some six million years between its initial development in the western Pacific and its appearance in southern California! If one wishes to include *Globorotalia tosaensis*¹⁴ within *G. truncatulinoides* then the apparent time-lag is possibly seven million years. Jenkins (1964) also recorded the initial appearance of *G. truncatulinoides* slightly above the base of the Pliocene in New Zealand, suggesting a time-

¹⁴ This species was described from upper Miocene deposits in Japan by Takayanagi and Saito (1962).

lag of perhaps one million years between its appearance there and in the tropics. Bolli (1965) demonstrated that *G. truncatulinoides* appears initially in the latest Pliocene in northern Venezuela, indicating that there are also discrepancies in the initial appearance of this species in the Atlantic Tertiary. Bolli (1965) also noted that this species is absent from Pliocene strata in Java and concluded the absence is due to critically high water temperatures. As noted by Bolli (1965) and recorded by Bradshaw (1959), *G. truncatulinoides* most commonly lives between latitudes of 20° and 40° today. However, it is living in the equatorial Pacific and constitutes over ten percent of some living populations (Bradshaw, 1959, p. 46). Finally, it was recorded by Bandy (1963c, 1964b) in equatorial Pliocene populations. Thus the absence of this species in the tropical Pliocene of Java (Bolli, 1965) may be due to parameters other than temperature.

The late appearance of *G. truncatulinoides* in southern California is curious in light of the present distribution of this species (Bradshaw, 1959; figs. 25 and 25). Its close faunal association with *G. inflata* (Bradshaw, 1959; Kustanowich, 1963, fig. 24) surely would have allowed it to be present in the *Globorotalia inflata* zone of the lower Pliocene (Text-figs. 31, 32, 33) if it had been living in the eastern North Pacific during this interval. The time-lag in appearance of this species in the eastern North Pacific serves as one more warning (Parker, 1965) against the tacit acceptance of the initial appearance of a planktonic species as a world-wide isochronous surface.

The latest Pliocene in southern California is marked by a relatively short period of subtropical temperature allowing the entrance of warm water biota. The warm period apparently occurred during the rapid regression and transgression of warm and cool isotherms past the southern California region just prior to the onset of the sustained cool temperature of the Pleistocene.

The initial appearances of *Globorotalia tumida* and "*Sphaeroidinella dehiscent*" in the uppermost portion of the Newport Mesa section (Text-fig. 27) represent prelusory indices of this zone. These occurrences also represent the only time other than the substantial subtropical period of the early Pliocene that this fauna appears in southern California. Two samples from the San Diego Formation (Text-fig. 11; Table 4) illustrate the subtropical aspect of this zone. Planktonic trends in these two samples indicate that the strata exposed at Pacific Beach encompass the later portion of

a warm period and the initial phase of an alternating period of cool surface temperature (Table 4). Both samples contain tropical elements, however, the stratigraphically lower sample (sample 1) is characterized by a dextral population of *Globigerina pachyderma*, a relatively low abundance of *G. bulloides*, and a relatively high percentage of *Globigerinoides ruber*. Furthermore, this sample contains a significant percentage of *Globigerinoides trilobus trilobus* as well as marginal percentages of *G. conglobatus*, *Globoquadrina conglomerata*, *Globorotalia inflata*, and *G. menardi tumida*. The stratigraphically higher sample is characterized by a sinistral population of *Globigerina pachyderma*, a relatively high percentage of *G. bulloides*, and only a few specimens of tropical species (Table 4). Thus the lower portion of the San Diego Formation at Pacific Beach (Tert-fig. 11) was deposited during a period of subtropical temperature perhaps reaching 20° to 22°C whereas the upper portion was deposited during a period of decreasing surface temperature perhaps as low as 13° to 11°C.

The benthic fauna of portions of the San Diego Formation include high percentages of *Hanzawaia nitidula* previously cited as living most abundantly today on subtropical and tropical shelf areas (Bandy and Arnal, 1957; Bandy, 1963b). Molluscan assemblages within the formation are also similar to Recent faunas off the central and lower Baja California coast (Hertlein and Grant, 1960; Allison, 1964). The late Pliocene-early Pleistocene incursions of warm water so clearly defined in the San Diego Formation are also represented by similar molluscan assemblages to the north in the Capistrano area (Vedder, 1960), Santa Monica area (Hoots, 1931), in the upper Pliocene Foxen Mudstone of the Santa Maria Basin (Woodring and Bramlette, 1950). Micropaleontologists have generally overlooked this relatively short warm water phase in the latest Pliocene of southern California. However, both planktonic and benthic foraminiferal assemblages corroborate molluscan data in regard to the subtropical nature of the biozone and indicate that it represents a unique and important horizon quite useful in regional planktonic correlations. A small but interesting detail of this biozone is the persistent occurrence in most localities of relatively high numbers of shallow water brachiopods, a phylum absent from most Tertiary deposits in California.

PLEISTOCENE TRENDS

Although Pleistocene planktonic assemblages were not specifically studied during this investigation it is interesting to record their known

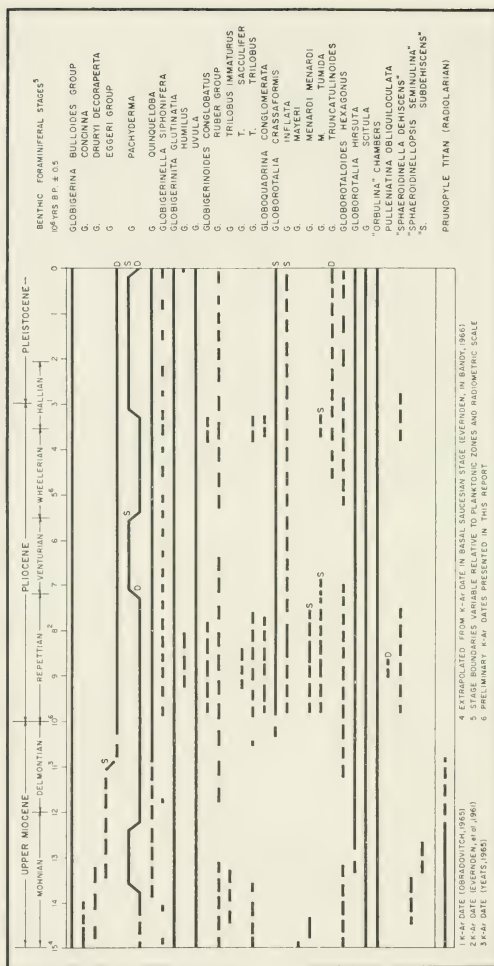
specimens of *Globigerina pachyderma*. Thus the sustained period of cool surface temperature traditionally associated with the Pleistocene at this latitude appeared much earlier than heretofore suspected. Presumably a closely spaced sampling and analysis of planktonic faunas from both these units would reveal some oscillation of isotherms during this relatively long period, however, no such study has been published to date. Nevertheless, inspection of spot samples within these units and from other Pleistocene sections in southern California has not revealed to the writer any planktonic assemblage indicative of a surface temperature significantly higher than that which presently prevails off the coast; conversely most assemblages infer temperatures much lower than those which occur today (Bandy, 1960a). Consequently, it is assumed that oscillations of mean annual surface temperature during the Pleistocene ranged between 10° and 18°C at this latitude.

Investigation of coiling ratios of *Globigerina pachyderma* within dated cores in basins off the southern California coast suggest that the present temperature profile was achieved 11,000 years B.P. (Bandy, 1960a, 1966c). Whether one wishes to utilize this horizon as the Pleistocene-Recent boundary is arbitrary especially in view of the effective glacial cover and ice pack still remaining at polar regions.

SUMMARY OF LATE TERTIARY PLANKTONIC TRENDS

In reviewing the general middle Miocene through Pleistocene planktonic trends presented above it is clear that the California Current (Text-fig. 23) has represented the single most important factor governing the character of planktonic assemblages in southern California. Because this eastern boundary current has its source at high latitudes, subarctic and cool temperate faunas dominate most Miocene through Pleistocene faunas. *Globigerina concinna* seems to have been the predominant subarctic and cool temperate species during the early and middle Miocene whereas *G. bulloides* and *G. pachyderma* dominate assemblages which lived from late Miocene to the present.

Variations in the character and composition of the late Tertiary assemblages can be directly attributed to the fact that southern California lies at the distal end of the California Current. The zone of mixing between the cool California Current and warm equatorial water is presently located 10°-15° south of southern California; the position of this zone has varied in the past. Fluctuations in the latitudinal position of tempera-



Text-figure 34.— Summary range chart of planktonic Foraminifera in the late Tertiary of southern California. Solid lines represent common occurrences whereas hatched lines represent marginal abundances. Alignment of the radiometric scale is based on dates available in literature, preliminary K-Ar dates presented in this report, and previous alignments presented by other investigators (Evernden, Savage, Curtis, and James, 1964; Bandy, 1966a). K-Ar dates reported by Dymond (1966, *Science*, vol. 152, pp. 1239-1241) from the MOHOLE cores suggest the upper Miocene zone of sinistral coiling *G. pachyderma* maybe as young as 11.0 x 10⁶ yrs. B.P. requiring an adjustment in the Miocene part of the range chart.

turesensitive planktonic faunas with time mirror the poleward and equatorward movement of various isotherms past the coast of southern California. Periods of polar refrigeration, glaciation, and formation or formation of sea ice in the high latitude source area are distinguished by the presence of a subarctic fauna in southern California. Conversely, interglacial or warm phases are reflected by poleward migration of warm temperate and tropical elements.

A summary chart is presented of the ranges of various planktonic species within the late Tertiary of southern California (Text-fig. 34). It should be noted that ranges of species are plotted against an absolute time scale constructed from available radiometric dates within the middle and late Tertiary of California. Although radiometric control of the ranges presented is far better than for any other comparable late Tertiary marine sequence it is still a somewhat speculative scale. More dates are needed to confirm and adjust the present interpretation (Text-fig. 34)¹⁵.

Regardless of future adjustments in scale it seems an advance of sorts to present planktonic ranges against this framework rather than simply noting their association with time-transgressive lithologic units or benthic stages. The relative stratigraphic sequence of planktonic forms will remain approximately the same regardless of future adjustments in the radiometric scale and consequently serve as dimensionless isochronous surfaces on a local level and on a restricted regional scale. Furthermore, it is safe to assume that radiometric dates will never be available for every section studied. Thus, if the most useful planktonic horizons are bracketed by radiometric dates in specific areas the radiometric data can also be extended with a fair degree of reliability. The scale and range chart presented (Text-fig. 34) represent an initial step in this direction.

Inspection of the summary diagrams (Text-figs. 34, 35) and cumulative frequency diagrams presented earlier suggest that planktonic assemblages deposited in southern California between 15×10^6 and 11×10^6 years B.P. can be divided into nine major zones (Text-fig. 35) on the basis of dominant faunal elements. Furthermore, the sequence contains at least 13 planktonic indices. The most useful indices within the sequence examined are from oldest to youngest: (1) the upper limit of *Globorotalia mayeri* (2) the lower limit of the upper Miocene zone of sinistrally coiling *Globigerina pachyderma* (3) the upper limit of *Sphaeroidinellopsis subdehiscens* (4) the upper limit of the upper Miocene zone of sinistrally

¹⁵ See note added in proof on Text-fig. 34.

coiling *Globigerina pachyderma* (5) the upper limit of the radiolarian *Prunopyle titan* (6) the lower limit of "*Sphaeroidinella debiscens*" (7) the abundant *Globorotalia inflata* zone (Text-figs. 31, 32, 33) (8) the lower limit of the mid-Pliocene, sinistrally coiling *Globigerina pachyderma* zone (9) the upper limit of the mid-Pliocene sinistrally coiling *Globigerina pachyderma* zone (10) the lower limit of *Globorotalia truncatulinoides* (11) the uppermost Pliocene zone of subtropical species ("San Diego horizon") (12) the lower limit of Pleistocene sinistrally coiling *Globigerina pachyderma* zone and (13) the dextrally coiling *Globigerina pachyderma* zone from 11,000 years B.P. to the Recent.

Those indices (Text-fig. 34), together with the zonal sequence (Text-fig. 35), provide a late Tertiary planktonic scale with an approximate precision of 1 to 1.5×10^6 years. While the nine faunal zones (Text-fig. 35) are principally a response to changes in surface temperature the various indices (Text-fig. 34) allow easy distinction between the recurrent and similar subarctic temperate, and subtropical faunas (Text-fig. 35).

Correlation of the oscillatory temperate planktonic sequence in southern California with the "standard" tropical planktonic zonation is hindered by: (1) the random occurrence and marginal abundances of tropical species within the late Miocene (2) lack of a well-established Pliocene zonation in the tropical Pacific. Despite these obstacles an attempt has been made to align the tropical and southern California planktonic zonations (Text-fig. 35). The general philosophy of this correlation is that tropical planktonic index species likely survived for longer periods within tropical regions than in areas affected by cool eastern boundary currents. Thus the uppermost occurrence of *Globorotalia mayeri* and *Sphaeroidinella subdebiscens* in southern California are assumed to be older than the final appearances of these species in the tropics (Text-fig. 35). Although *Globigerina nepenthes* has not been reported from southern California to date, equivalent horizons are assumed to be present between the uppermost occurrence of *Globorotalia mayeri* and the initial appearance of "*Sphaeroidinella debiscens*" (Text-fig. 35).

Parker (1965b) has currently studied the Pliocene planktonic sequence in the tropical Pacific, and has noted the initial appearance of "*Sphaeroidinella debiscens*" at about the Miocene-Pliocene boundary. This species also occurs in Lower Pliocene sediments of southern California as documented earlier. Thus the assumed discrepancy between the initial appearance of this form in the two areas may not be as great as depicted on

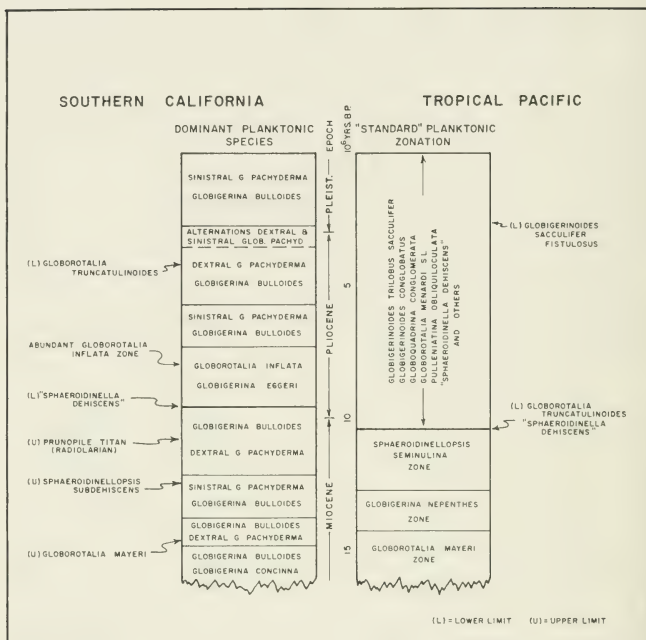
Text-figure 35 due to the intrusion of warm isotherms into southern California during this period. However, the apparent lengthy delay between the first occurrence of *Globorotalia truncatulinoides* in tropical and warm temperate areas and in southern California dictates the need for caution in using tropical planktonic indices in temperate regions.

PALEO-OCEANOGRAPHIC INFERENCES

A comparison of the upper Tertiary planktonic sequence in southern California (Text-figs. 34, 35) with the modern planktonic facies in the marginal eastern North Pacific (Text-fig. 25) suggests that there have been at least three major periods of subarctic surface temperature and two periods of subtropical surface temperature during the last 15 million years. Without reviewing all the faunal details and analogies discussed earlier and presented graphically, the following general trends are apparent.

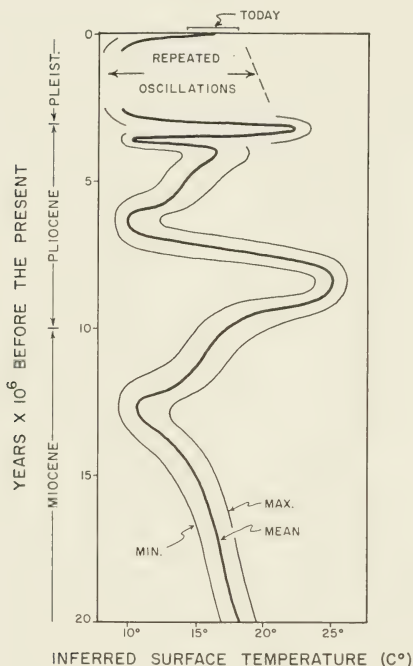
Although tropical species are present in late middle Miocene sediments (Text-fig. 27; Lipps, 1964) the preponderance of *Globigerina bulloides* and *G. concinna* indicate surface temperatures were only slightly higher than occur offshore today. Temperature declined further in the late Miocene as indicated by increasing percentages of sinistrally coiling specimens of *G. pachyderma* culminating in a period of subarctic surface temperature possibly reaching 10°C about 12 to 13 million years B.P.¹⁶. The reappearance of dextral specimens of *G. pachyderma* indicates surface temperature began to increase again in the latest Miocene. Continued increase in surface temperature allowed subtropical and tropical species to migrate north into southern California about 9.5×10^6 years B.P. Abundance of robust *Globigerina eggeri* and *Globorotalia inflata* along with significant percentages of keeled globorotalids (Text-figs. 31, 32, 34) suggests that the zone of mixing between the California Current and equatorial water was located far north of its present position during the early Pliocene. Surface temperatures during this period may have exceeded 25°C. Thus the Miocene-Pliocene boundary as defined in this report is bracketed by incursions of unusually cold and unusually warm water planktonic assemblages compared with the "standard" modern planktonic fauna at this latitude today (Text-fig. 28). Continued oscillations of isotherms are indicated by mid-Pliocene and Pleistocene zones of sinistrally coiling *G. pachyderma* (Text-fig. 34; Bandy, 1960a). Surface temperatures probably declined to 10°C or below during both these intervals. The severity of the

¹⁶ See note added in proof to Text-fig. 34.



Text-figure 35.—Planktonic foraminiferal zonation of the late Tertiary in southern California and suggested correlation with the "standard" tropical planktonic zonation. Southern California zonation is based on the dominant members of various temperature-controlled planktonic biofacies and accompanying planktonic indices. "Standard" tropical Pacific zonation is adapted from Bandy (1963c; 1964b), Wade (1964), Parker (1965b), and Todd (1964). A detailed zonation of the Pliocene and Pleistocene in the tropical Pacific is currently lacking.

Pleistocene marine climate at this latitude is emphasized by the appearance of glaciers in the nearby mountains (Ingle and Moran, 1958; Sharp, Allen, and Meier, 1959). The intervening late Pliocene warm period is characterized by a fauna similar to that living off the coast today. Approximately 5×10^6 years B.P. rapid fluctuations in surface temperature were initiated (Text-fig. 29) culminating in the reappearance of a subtropical fauna about 3.5×10^6 years B.P. (Text-figs. 34, 35). Radiometric dating



Text-figure 36.—Variation in sea surface temperature during the late Tertiary at latitude 33° in the marginal eastern North Pacific. Temperatures are inferred from variation in temperature sensitive planktonic foraminiferal faunas within late Tertiary bathyal sequences exposed in southern California and comparison with the distribution of identical species in the marginal eastern North Pacific today. Alignment of the radiometric scale is identical to that presented in Text-figure 34.

(Obradovich, 1965) indicates that the long period of subarctic temperatures marking the Pleistocene began about 3×10^6 years B.P. and has continued with limited oscillations to the present (Bandy, 1960a).

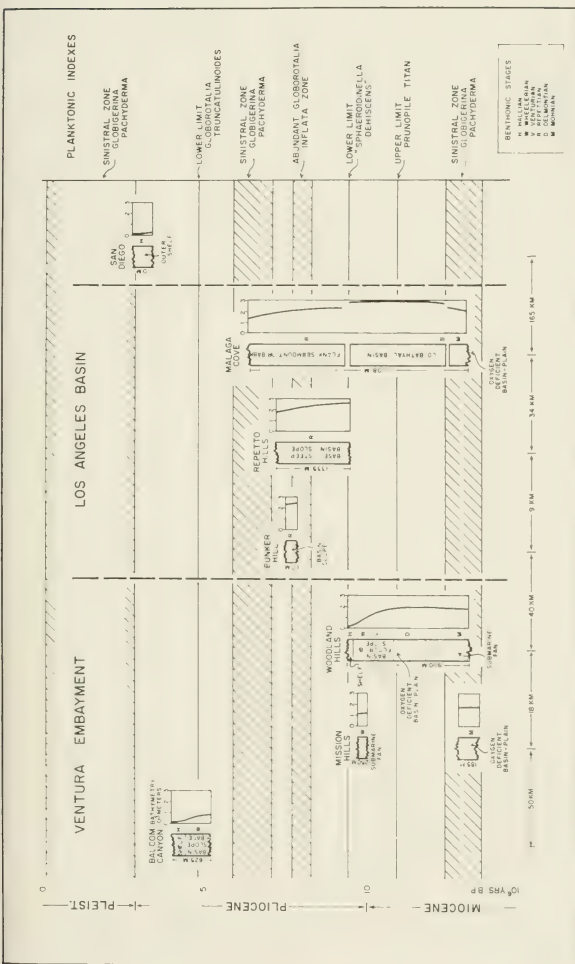
Variations in surface temperature inferred by planktonic Foraminifera were plotted against the available radiometric scale (Text-fig. 36). The resulting curve suggests an overall decrease in surface temperature with time similar to that deduced from megafaunal data by Durham (1950).

However, the magnitude of oscillations is much greater than depicted by Durham (1950). Indeed, variations in geographic distribution of planktonic Foraminifera since the Cretaceous (Bandy, 1960c) indicate that these systematic oscillations during the late Tertiary were simply a continuation of a large scale interaction initiated in the Paleocene with a major poleward expansion of warm isotherms from the equatorial regions. Amplitude of surface temperature curves with time at mid-latitude stations has apparently decreased since the Cretaceous while frequency of oscillation has increased. The fact that this overall action might be described by an attenuated sinusoidal wave equation indicates that the process is not random and related to some unique coincidence, but may be predictable and related to a major perturbation of the earth.

Whatever the mechanism of polar refrigeration the inferred surface temperature of 11° - 12°C at latitude 33° during the late Miocene suggests that at least formation of sea ice may have occurred in the Aleutian area during this interval. The previously cited evidence of Miocene glaciation in the Antarctic (Rutford, Craddock, and Bastien, 1965) lends some support to this view. Moreover, Bandy (1965, 1966b) recently discussed the case for Miocene-to-Recent glaciation in the Antarctic; the inferred mid-Pliocene period of subarctic surface temperature in southern California (Text-fig. 36) offers some evidence that sea surface temperatures also declined sharply in high latitude areas of the North Pacific. Emiliani and Flint (1963) reviewed evidence indicating that Antarctica was fully glaciated by the late Pliocene; it seems logical to assume this period of sustained glaciation was preceded by oscillatory warm and cool phases at both poles based on the Pleistocene record. Thus, the inferred record of oscillations in temperature within the California Current at latitude 33° during the late Tertiary (Text-fig. 36) fits a pattern intimated by other lines of evidence.

PLANKTONIC CORRELATION OF EPICONTINENTAL DEPOSITS

In reviewing the distribution and sedimentary history of the numerous modern basins off southern California (Text-fig. 2; Gorsline and Emery, 1959; Emery, 1960) it seems reasonable to expect that the now-filled Tertiary basins onshore (Text-fig. 1-4) have had similar independent tectonic and sedimentary histories. Thus, benthic faunas representative of different depth habitats (Table 1) must have appeared at different times



Text-figure 37.—Planktonic correlation of principal sections utilized in the Ventura, Los Angeles, and San Diego areas. Note that the sections are plotted against the estimated alignment of the planktonic indices and the available radiometric scale as presented on Text-figure 34. Thus the length of each column roughly corresponds to the length of time necessary for deposition of each section; stratigraphic thicknesses are given in meters at the side of each column. Paleobathymetric curves and paleoenvironmental classification of sedimentary and benthic biofacies are presented as interpreted in the early portion of the report (Text-figs. 16-22). The position of benthic faunas representative of the traditional benthic foraminiferal stages is noted by a code letter.

within these basins. Evidence has already been presented (Text-fig. 14) and cited (Bandy, 1960a) illustrating the time transgressive nature of benthic faunas within two of these basins. The planktonic zonation and indices outlined in the late Tertiary of southern California in this report (Text-figs. 34-36) allow correlation of the dissimilar paleobathymetries and sedimentary regimes represented within the stratigraphic columns of several basinal areas.

Rather than plotting the sections in the conventional manner, each column was aligned with the combined planktonic and radiometric scale proposed above (Text-fig. 34). The resulting diagram thus depicts the approximate duration of each environment represented within a stratigraphic column rather than the actual thickness of each facies (Text-fig. 37). The suggested paleobathymetric curves for each section are also presented as deduced from benthic faunal groups earlier in the report (Text-figs. 16-22). It is readily seen that the synchronous planktonic horizons within each section provide an excellent means of correlating dissimilar sedimentary events within the confines of a single basin or within separate basin areas (Text-fig. 37).

Noting the absolute thickness of each section and the relative length of time represented by each column gives a rough measure of the differential rate of sedimentation in the various areas (Text-fig. 37). However, it must be emphasized that several sections contain more than one sedimentary facies ranging from coarse instantaneously deposited submarine fan deposits to slowly accumulating diatomaceous sequences. Consequently, the overall rate of sedimentation for a particular section may be heavily modified by a rapidly deposited facies. Although the diagram is self-explanatory it is of interest to note several implications of the correlations presented.

The column possessing the greatest duration but shortest absolute thickness is the Malaga Cove section (Text-fig. 37). This is in accord with the paleoenvironmental interpretations of the facies represented within this sequence as all three facies (diatomaceous-oxygen-deficient basin plain; radiolarian-rich lower bathyal basin; glauconitic-foraminiferan rich bank or seamount deposits) are characterized by relatively low rates of sedimentation. The planktonic correlations also indicate that these foraminiferan barren-radiolarian rich sediments were accumulating at lower bathyal depths in the Los Angeles Basin while laminated diatomaceous shales containing an impoverished benthic fauna were accumulating 50 km to

the north in the San Fernando Basin region of the Ventura Embayment (Text-fig. 37).

Correlation of the Malaga Cove and Woodland Hills sections on planktonic data (Text-fig. 37) also illustrates that Mohnian Stage faunas existed for a longer period in the San Fernando Basin than in the western Los Angeles Basin. Furthermore, Delmontian faunas appear much later in the Woodland Hills section than in the Palos Verdes Hills-Malaga Cove sequence. Indeed, Delmontian faunas disappeared due to subsidence in the Malaga Cove section before the final appearance of faunas of the Mohnian Stage in the Woodland Hills area (Text-fig. 37).

Another interesting aspect of these correlations is that they illustrate the time-transgressive nature of benthic faunas in the eastern and western portions of the Ventura Embayment thus confirming previous speculations by other investigators (Holman, 1958; Bandy, 1960a). The chronologic relationship between the Woodland Hills and Balcom Canyon sections (Text-fig. 37) distinctly indicates that faunas of the Wheelerian and Hallian Stages in the eastern portion of the embayment were deposited during the early Pliocene whereas similar shelf faunas were deposited during the late Pliocene in the western or seaward portion of the embayment. In this regard it is also of interest to recall that the Hallian or shelf-depth biofacies characterizing the lower Pliocene in the eastern portion of the embayment contain large percentages of the Panamanian province species *Hanzawaia nitidula* (Text-fig. 20). The equivalent shelf biofacies deposited during the late Pliocene in the western portion of the embayment lacks this species and contains a suite of species characteristic of much cooler temperatures (Text-fig. 29), consistent with interpretations of surface temperature during this interval (Text-fig. 36).

As planktonic faunas are analyzed from additional sections in this area it is safe to anticipate the resulting correlations will provide further evidence of the time transgressive nature of the various benthic faunal groups (Table 1). More importantly, however, correlations such as these provide a means for deciphering the independent tectonic and sedimentary histories of the complex of late Tertiary basins in southern California, in Baja California, and offshore within the continental borderland. Because previous interpretations of sediment age and related sedimentary events have been based almost exclusively on time transgressive benthic Foraminifera it can also be anticipated that a general reinterpretation of basin history will result from forthcoming analysis of planktonic faunas.

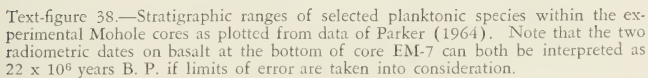
CORRELATION OF EPICONTINENTAL AND ADJACENT DEEP-SEA SEDIMENTS

At the moment there are only two places in the world where a direct correlation can be made between planktonic biofacies in a Tertiary epicontinental sequence and adjacent deep-sea deposits. The first is the southern California-Baja California area of the experimental MOHOLE cores (Riedel, Ladd, Tracey, and Bramlette, 1961; Parker, 1964) and the second is the southeastern continental margin of the United States off northern Florida where the JOIDES sampling program is in progress (Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965).

Due to the mild tectonic history of the southeastern margin of the continent the JOIDES cores penetrated a sequence of Miocene through Paleocene formations essentially identical with those found onshore. The deepest sediments sampled were deposited at about 1,000 meters and most were shelf-depth facies; thus these cores did not penetrate a deep ocean basin deposit in the traditional sense.

In contrast the experimental MOHOLE cores were obtained at a depth of 3,566 meters and penetrated a 182 meter sequence of Pliocene through Miocene calcareous and siliceous ooze. The drilling area lies directly west of the irregular continental slope on a gently rolling portion of the abyssal plain termed the Guadalupe *arrugado* by Krause (1961, 1965). Riedel, Ladd, Tracey, and Bramlette (1961) outlined the physical stratigraphy of the cores. Martini and Bramlette (1963) described the sequence of nannoplankton and concluded late Miocene and Pliocene forms were present but noted correlations were difficult due to the influence of the cool California Current in the Miocene. Most recently Parker (1964) described the Foraminifera from selected horizons in the cores and Krueger (1964) obtained two K-Ar dates on basalt at the base of core EM-7.

The stratigraphic ranges of selected planktonic Foraminifera within the MOHOLE cores have been plotted from data by Parker (1964) along with other pertinent aspects of the cores (Text-fig. 38). Comparison of the planktonic sequence in these cores (Text-fig. 38) with the ranges and characteristics of planktonic species in southern California (Text-figs. 34-35) reveals a strikingly similar sequence despite the characteristically large difference in total sediment thickness in the two environments. Parker (1964) correlated the major sequence with the Luisian and Mohnian Stages of California (Text-fig. 3) and noted the highest sample was Pliocene.

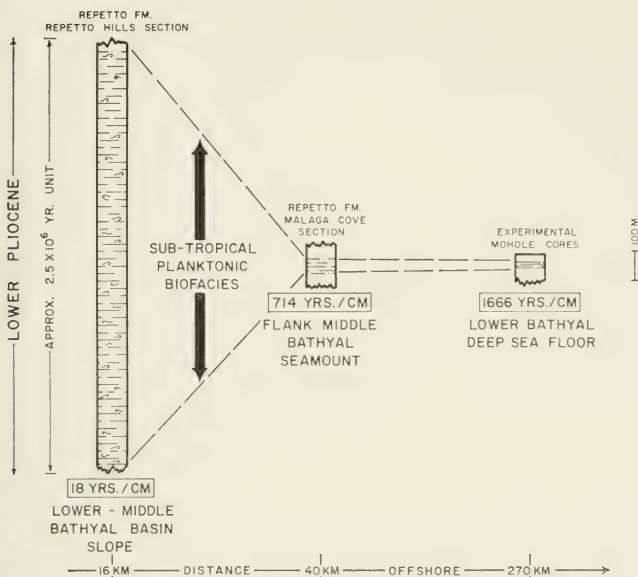


The planktonic indices recognized in the southern California (Textfigs. 34-35) are present in the MOHOLE cores. The two most outstanding horizons are the base of the Upper Miocene zone of sinistrally coiling *Globigerina pachyderma* and the initial appearance of "*Sphae-*

roidinella debiscens" in the highest core segment (Text-figs. 34, 35, 38). Parker (1964) also noted the presence of a form tentatively identified as *Globorotalia* cf. *G. mayeri* in the lowermost portion of the cores (sample 2 and 3). If this represents the uppermost range of this species it is difficult to envision the same horizon as being equivalent to the *Globorotalia fohsi* zone of the tropics as proposed by Parker (1964) in light of the difference in range of these two species in the "standard" sequence of the tropical Pacific (Bandy, 1964b; Wade, 1964). However, it must be noted that *Globorotalia mayeri* does range to almost the base of the zone of sinistrally coiling *Globigerina pachyderma* in the Newport Mesa section (Text-fig. 27) suggesting it ranges higher than recorded to date in the MOHOLE sequence. Parker (1964) cited the presence of "*Orbulina suturalis*" as further evidence of the equivalence of the lower portion of the cores to the *Globorotalia fohsi* zone. Reliance on various "*Orbulina*" morphotypes for stratigraphic purposes appears to be open to question in light of the multiple origin of these forms and the time-lag in appearance of "*Orbulina*" stages in high latitudes (Bandy, Ingle, and Frerichs, 1965; Bandy, 1966; Jenkins, 1966).

Due to lack of core, Pliocene species appear abruptly in the isolated and highest MOHOLE sample recovered (Text-fig. 38). As discussed earlier the simultaneous occurrences of "*Sphaeroidinella debiscens*" and *Sphaeroidinellopsis seminulina* within the same horizon has not been observed to date in southern California (Text-figs. 34-35) nor has *Globigerina druryi decoraperta* been seen in the lower Pliocene sediments of this area. These associations within the upper MOHOLE sequence (Text-fig. 38) suggest that the Pliocene horizon represented there is slightly older than lower Pliocene assemblages described from the Los Angeles Basin (Text-figs. 31-32). In any event the absence of *Globorotalia truncatulinoides* in the Pliocene of the MOHOLE sequence corroborates its peculiar absence in adjacent lower Pliocene sequences (Text-figs. 34-35). The considerable number of tropical taxa within the Pliocene of the MOHOLE sequence is also consistent with the lower Pliocene of the southern California sections (Text-figs. 34-35) and further marks the intrusion of warm isotherms into the region during this period.

The presence of the lower Pliocene subtropical biofacies within the MOHOLE sequence (Text-fig. 38) allows an interesting if somewhat speculative correlation to be made. Correlation of the relative position of the planktonic data in the MOHOLE sequence with the combined plank-



Text-figure 39.—Correlation of the lower Pliocene subtropical planktonic biofacies within the Repetto Hills section, Malaga Cove section, and the experimental Mohole cores. Thickness of the lower Pliocene biofacies in the Mohole cores was estimated by comparison of relative time between similar planktonic indices in southern California. Distance offshore represents distance from the Pliocene strand line. Relative rates of sedimentation are given in terms of years per centimeter of deposition (uncorrected for compaction).

tonic-radiometric scale constructed for southern California suggests that there are at least 15 meters of lower Pliocene strata in the area of the MOHOLE cores. It is assumed this thickness also represents the duration of the apparent incursion of warm isotherms during the early Pliocene (Text-figs. 35-36). Assuming the above relationship, correlation of the lower Pliocene subtropical planktonic biofacies in the Repetto Hills section (Text-fig. 32), Malaga Cove section (Text-fig. 31), and the MOHOLE cores (Text-fig. 38) allows the relative rate of sedimentation to be assessed on a basin slope, isolated bank, and the deep-sea floor (Text-fig. 39). Sug-

gested alignment of the planktonic zones and data with the available radiometric scale indicates the duration of the subtropical biofacies was roughly 2.5 million years (Text-fig. 34). Thus relative rates of sedimentation were estimated for each environment by dividing the 2.5 million year interval by the length of sediment containing the subtropical biofacies. The resulting values (Text-fig. 39) do not take into account gravity compaction and thus represent minimum values. Transformed and corrected values are presented on Table 5.

Comparison of the rate of deposition deduced for the steep Pliocene basin slope in the Repetto Hills (18 years/cm) with modern rates of deposition off southern California (Bandy, 1960a) indicates that the Pliocene value is in accord with rates of deposition on slopes of modern nearshore basins (Table 5).

The early Pliocene depositional rate calculated for the MOHOLE core appears reasonable in light of other deep-sea areas (Table 5) although intermittent and instantaneous introduction of pyroclastic material at this locality (Riedel, Ladd, Tracey, and Bramlette, 1961) undoubtedly would affect specific rates of sedimentation at various horizons in the cores. Considering the proximity of this locality to the continental slope and the approximate rate of deposition on the slope (Table 5) suggests the estimated value of 0.6 cm/1,000 years may be low. However, Krause (1961, 1965) showed this area to be an anticlinorium and consequently characterized by a low rate of sedimentation as opposed to the nearby Cedro Deep and other areas directly at the base of the continental slope.

There are no values available for the rate of deposition on a modern seamount or bank, however, many investigators have described abundant evidence illustrating that these features collect little sediment (Emery, 1960, p. 210) due to their isolation. The calculated rate of deposition for the flank of the early Pliocene seamount or bank at Malaga Cove (Text-fig. 39; Table 5) is consequently of some value in understanding sedimentation on modern seamounts.

TABLE 5. Comparison of rates of sedimentation in Recent and early Pliocene sedimentary environments.

Area	yrs/cm	Rates of Sedimentation	
		uncorrected cm/1,000 yrs	corrected ¹ cm/1,000 yrs
Recent			
Nearshore basin slopes off southern California ²	25	40	
San Pedro Basin ^{3 4}	19	54	
Western slope of the Gulf of California ³	33	30	
Continental slope off California	53	19	
North Pacific ^{3 5}	10,000—	0.1—	
	2,500	0.4	

Early Pliocene ⁶			
Steep basin slope, Repetto Hills section	18	56	77
Flank of seamount or bank, Malaga Cove section	714	1.4	2.2
Deep-sea floor, experimental MOHOLE cores	1,666	0.6	0.8

¹ Estimated maximum correction for gravity compaction = 30 percent of original thickness (Van Andel, 1964).

² Bandy (1960a).

³ Van Andel (1964).

⁴ Emery and Bray (1962).

⁵ Goldberg and Koide (1962).

⁶ Depositional rates calculated utilizing estimated duration of subtropical planktonic biofacies in southern California.

UPPER TERTIARY PLANKTONIC BIOFACIES VARIATION ALONG THE MARGINAL EASTERN NORTH PACIFIC

Having identified several distinct variations in surface temperature within the upper Tertiary sequence of southern California (Text-figs. 34-36), it is logical to look for evidence of these paleo-oceanographic variations in other areas under the influence of the California Current system. A search for planktonic foraminiferal evidence of these variations is hindered by the lack of comparable analyses of planktonic Foraminifera from upper Tertiary strata along the west coast of North America. Nevertheless, enough data are at hand to construct an interesting picture of late Tertiary paleo-oceanographic changes along the marginal eastern North Pacific.

Fowler (1965) recently presented an excellent quantitative analysis of foraminiferal faunas within the upper Miocene Montesano Formation of Washington (Text-fig. 12). Fowler (1965) also included an analysis

of planktonic Foraminifera from the Pliocene Quinault Formation in an adjacent area (Text-fig. 12). Both of these formations represent bathyal deposits in part and are located at about latitude 47° which is 13° north of the southern California area. Bradshaw's (1959) work together with inspection of modern planktonic biofacies along the marginal eastern North Pacific (Text-fig. 25) indicate that subarctic planktonic faunas characterize this area today. More importantly, planktonic assemblages are dominated by sinistrally coiled specimens of *Globigerina pachyderma*.

Because of the critical nature of planktonic trends at high latitudes, ranges and characteristics of planktonic species within the Montesano and Quinault Formations were plotted from Fowler's (1965) data (Text-fig. 40). Unfortunately the lower portion of the Montesano Formation was deposited at inner shelf depths and consequently lacks abundant planktonic Foraminifera.

The planktonic species present with the two formations (Text-fig. 40) are typical of high latitude faunas today (Text-fig. 25) with the exception of *Globorotalia crassaformis*.¹⁷ This species has not been reported as living in the North Pacific (Bradshaw, 1959; Smith, 1963, 1964) but is a common warm temperate species in the South Pacific (Kustanowich, 1963) today; it has an erratic distribution in other warm temperate and tropical seas (Parker, 1965). In light of the warm temperate environment of this species in modern seas it is interesting to observe that its distribution in the Montesano and Quinault Formations is coincident with horizons containing dominantly dextrally coiling specimens of *Globigerina pachyderma* (Text-fig. 40) which is also indicative of a temperate water mass. Furthermore, *Globorotalia crassaformis* is absent from the overlying zone dominated by sinistrally coiling *Globigerina pachyderma* (Text-fig. 40). The association of *Globorotalia crassaformis* and dextral population of *Globigerina pachyderma* indicate that surface temperatures during the late Miocene and early Pliocene of this area were significantly higher than occur at this latitude today.

Comparison of the high latitude planktonic sequence recorded by Fowler (1965; Text-fig. 40) with the Miocene-Pliocene planktonic sequence in southern California (Text-figs. 34-36) indicates that the inferred warm interval within the Montesano and Quinault Formations correlates with the

¹⁷ Fowler (1965) recorded both *Globorotalia crassaformis* and "*G. puncticulata*"; the writer included both forms within *G. crassaformis* as discussed by Parker (1962).

late Miocene-early Pliocene period of warm temperate and subtropical planktonic biofacies noted 13° to the south in the Modelo and Repetto Formations. Moreover, the switch from a dextral to sinistral coiling direction exhibited by *Globigerina pachyderma* in the upper Quinault Formation (Text-fig. 40) appears to be synchronous with the mid-Pliocene zone of sinistral *G. pachyderma* in southern California. It thus seems inescapable that the late Miocene-early Pliocene incursion of subtropical and tropical planktonic biofacies in southern California was accompanied by the incursion of a temperate planktonic biofacies at latitude 47° and perhaps beyond. Mid-Pliocene refrigeration of the poles again drove cold isotherms within the California Current south, allowing subarctic faunas to extend at least as far south as latitude 30° (Text-figs. 34-36).

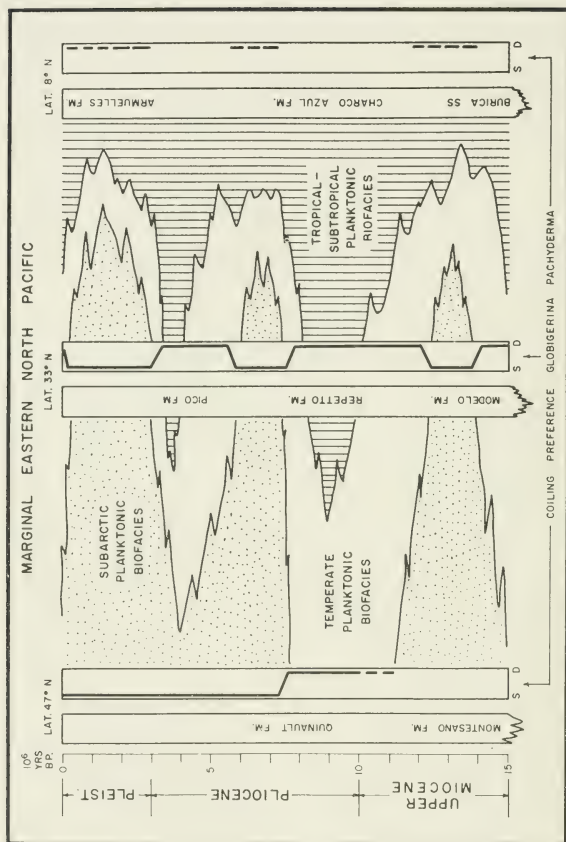
Modern quantitative analyses of upper Tertiary foraminiferal assemblages are completely lacking from areas south of southern California with the exception of Parker's (1964) report on the MOHOLE cores. These revealed a planktonic sequence essentially identical with that of southern California (Text-fig. 38). Despite the lack of pertinent foraminiferal analyses it seems reasonable to assume that planktonic faunas within the upper Miocene and Pliocene of the tropical eastern Pacific are composed almost exclusively of warm water species. Indeed, Coryell and Mossman (1942) recorded a typical suite of tropical planktonic species from the lower Pliocene Charco Azul Formation of Panama and Costa Rica, and Vaughan (1919) recorded exclusively Panamanian molluscan assemblages from mid-Miocene through Pleistocene sediments exposed in the Canal Zone. Although tropical faunas undoubtedly thrived in equatorial regions even during the Pleistocene, there is some probability that boreal species such as *Globigerina pachyderma* occurred in significant numbers in the tropical eastern Pacific during cold polar phases due to the increased speed and drive of the eastern boundary currents. Moreover the confluence between the California Current and equatorial waters may have been located up to 10° south of its present position during periods of maximum glaciation, thus allowing a more thorough mixing of temperate and tropical faunas. Further analyses are needed to explore this possibility.

Again noting the inferred upper Miocene-lower Pliocene temperate planktonic zone in the Montesano-Quinault sequence (Text-fig. 40) and assuming the permanence of warm water assemblages in the equatorial region, a generalized diagram depicting oscillations of planktonic biofacies can be constructed (Text-fig. 41). The tropical-subtropical planktonic

biofacies is characterized by a high percentage of *Globigerina eggeri* and a significant number of keeled globorotalioids, the temperate biofacies is characterized by abundance of dextrally coiled specimens of *Globigerina pachyderma* along with the transitional species *Globorotalia inflata* and *G. truncatulinoides*. Moreover, the subarctic fauna is characterized by a high percentage of sinistrally coiling specimens of *Globigerina pachyderma* (Text-fig. 41). Again estimated alignment of the absolute time scale is based upon the combined radiometric-planktonic scale given earlier (Text-fig. 34).

An immediate implication of the inferred oscillation of planktonic biofacies (Text-fig. 41), is that some presumably isochronous planktonic horizons may cross time lines due to migration. It is not logical that the inferred variations in surface temperature were "instantaneous" even in the geologic sense. In view of the constant equatorward transport within the California Current system it is likely that warming trends occurred at a much slower rate than did decreases in temperature at any given coastal station. Some support for this thought is reflected in the lengthy period of warm temperate waters during the late Miocene prior to the creation of truly subtropical conditions during the early Pliocene (Text-figs. 34-36). Conversely, equatorward drift would allow any effective lowering of temperature in the North Pacific to be sensed relatively rapidly at mid-latitudes or north of the zone of mixing. Following this reasoning, surfaces representing the initial appearance of tropical or warm temperate planktonic indices in the California Current system must transgress more time than a surface representing the initial appearance of a boreal species. The actual time discrepancies represented by oscillation of planktonic facies in the marginal eastern North Pacific (Text-fig. 41) must await more detailed studies of planktonic Foraminifera and accompanying radiometric dates at critical horizons.

Another major problem illustrated by the diagram of planktonic facies variation (Text-fig. 41) is that the commonly used planktonic indices for the basal Pliocene, namely "*Sphaeroidinella debiscens*," *Globorotalia inflata*, and *Globorotalia truncatulinoides*, are absent from upper Tertiary strata at high latitudes (Text-figs. 40, 41). It seems clear that an equivalent horizon is located somewhere within the zone of dextrally coiling *Globigerina pachyderma* (Text-fig. 41), but it is impossible to know the exact horizon. Thus these "boundary" criteria leave much to be desired since they cannot be used in all areas with equal effectiveness and synchronicity.



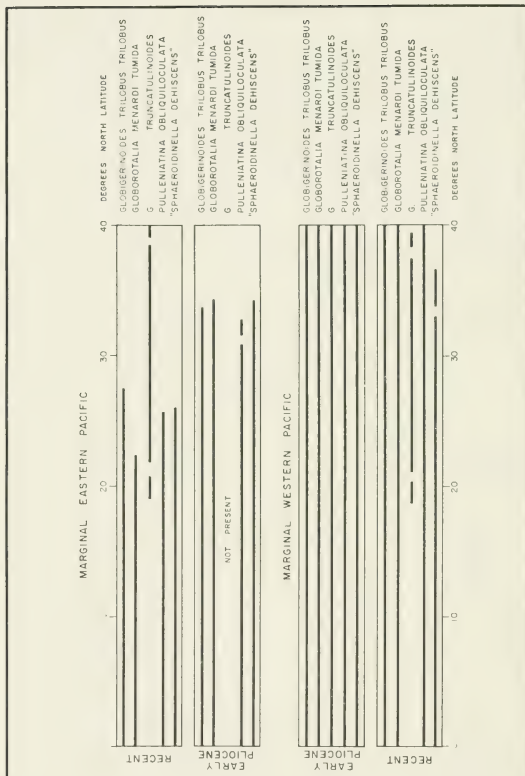
Text-figure 41.—Generalized diagram illustrating the transgressions and regressions of tropical, temperate, and subarctic planktonic foraminiferal populations along the marginal eastern North Pacific during the late Tertiary. Appearance of *Globigerina pachyderma* in the equatorial region during periods of polar refrigeration is assumed.

Assuming that the mechanism controlling the major oscillations of surface temperature outlined (Text-fig. 41) is a bipolar phenomenon, planktonic evidence of a somewhat similar sequence of events may eventually be established in the upper Tertiary rocks of the marginal eastern South Pacific.

COMPARISON OF UPPER TERTIARY PLANKTONIC BIOFACIES IN THE WESTERN AND EASTERN MARGINAL NORTH PACIFIC

The slow, cool, equatorward-moving California Current which has maintained a predominantly subarctic and temperate planktonic biofacies along the margin of the eastern Pacific is countered by the swift poleward-moving Kuroshio Current in the western North Pacific (Text-fig. 23). The effect of this clockwise circulation pattern on the distribution of modern planktonic species was illustrated earlier (Text-fig. 24). Because western boundary currents have their sources within the equatorial zone it cannot be expected that temperature oscillations such as were noted in the paleo-California Current system (Text-fig. 36) would have necessarily occurred simultaneously in the western Pacific. In fact, during periods of polar cooling, resultant compression of the equatorial current system likely caused acceleration of the Kuroshio Current, resulting in greater dispersion of tropical planktonic species northward.

One manner in which the past and present effect of the clockwise current system can be assessed is to note the horizontal (latitudinal) ranges of planktonic species during the early Pliocene and Recent in the western and eastern North Pacific (Text-fig. 42). Comparison of the distributions of the selected Recent and early Pliocene species indicates that although the early Pliocene was a time of maximum surface temperature in the eastern Pacific there was still a 5° - 10° difference of horizontal ranges in the two areas. The absence of *Globorotalia truncatulinoides* in the lower Pliocene of the eastern Pacific again suggests a delay in migration. In view of the clockwise current system and the delayed appearance of *G. truncatulinoides* in the eastern Pacific (Text-figs. 34, 42), it appears that this species entered California waters from the west. Furthermore, the difference in horizontal range of *G. truncatulinoides* in the Pliocene and Recent of the western Pacific suggests that this species initially migrated north from the tropical western Pacific during the late Miocene and thence

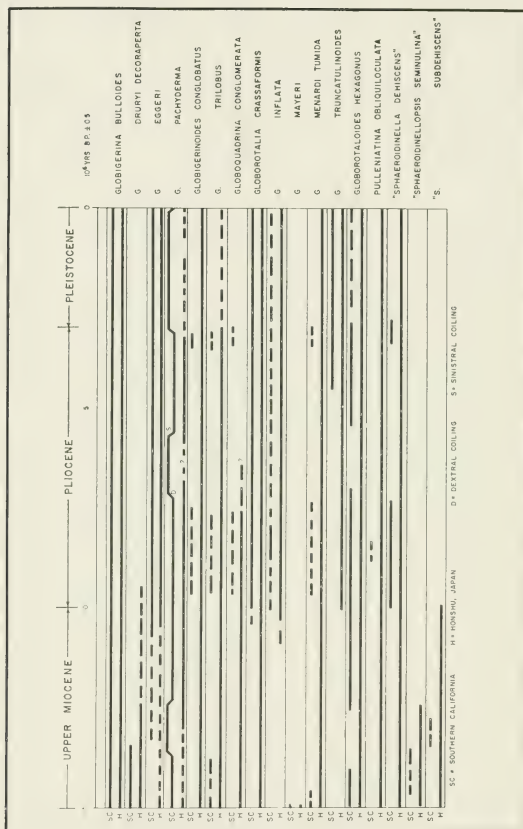


Text-figure 42.—Comparison of latitudinal distribution of selected planktonic Foraminifera in the marginal eastern and marginal western North Pacific during the Recent and Early Pliocene. Sources for Recent distribution are the same as given for Text-figure 24. Fossil distributions were compiled from Aoki (1963), Bandy (1963c, 1964b), Chang (1959; 1962), Coryell and Mossman (1942), Fowler (1965), Huang (1964), Parker (1964), and this report.

across the central Pacific filling during the late Pliocene the transitional niche it now occupies (Text-figs. 34, 41).

A more detailed view of differences in planktonic biofacies in the east and west margins of the North Pacific is obtained by noting the vertical ranges of selected planktonics within the upper Tertiary of the two areas (Text-fig. 43). The boreal species *Globogerina bulloides* and *G. pachyderma* are common in both sequences. However, there is no evidence indicating that *G. pachyderma* exhibits a sinistrally coiling tendency in any upper Tertiary horizon or in the Pleistocene (Ujiie, 1963) of eastern Honshu. As noted earlier, Saito (1963) illustrated that a boreal or subarctic fauna appears in northern Japan immediately after extinction of the *Globorotalia fohsi* fauna; tropical faunas continue to predominate in southern and central Japan.

The most striking differences in planktonic distributions are illustrated by the ranges of tropical and subtropical species. The rare occurrences of *Sphaeroidinellopsis seminulina* and *S. subdebiscens* in the upper Miocene of southern California are in marked contrast to the persistent and common occurrence of these morphotypes in the basal Pliocene of Japan. "*Sphaeroidinella debiscens*" has been recorded in the upper Miocene of Japan whereas it seems to occur consistently in the Pliocene elsewhere in the Pacific (Bandy, 1964a; Parker, 1964, 1965b). It is reported as sporadic in the latest Miocene by Bandy (1963c). *Pulleniatina obliquiloculata* ranges throughout the upper Miocene to the Pleistocene in Japan and the Philippines whereas it is recorded as a rare constituent of the lower Pliocene subtropical fauna in southern California (Text-fig. 43). *Globorotalia crassaformis* is also recorded well into the Miocene of Honshu and the Philippines whereas this species is restricted to highest Miocene through Pleistocene in the marginal eastern Pacific suggesting migration again occurred from west to east or the direction of prevailing currents. In fact, of the selected planktonic ranges illustrated (Text-fig. 43), the only range common to both areas is that of *Globorotalia inflata*, a warm temperate transition zone species (Bradshaw, 1959; Kustanowich, 1963). Thus the initial occurrence of *Globorotalia inflata* appears to be synchronous on both margins of the North Pacific Basin. Other examples from Text-figure 43 could be cited, however, the differences are apparent upon inspection. The principal point illustrated by this range chart (Text-fig. 43) is that a persistent subtropical and tropical planktonic fauna has prevailed in Japan since at least the mid-Miocene whereas subtropical faunas in southern



Text-figure 43.—Comparison of vertical ranges of selected planktonic Foraminifera in the upper Miocene through Pleistocene of central Honshu, Japan, and southern California. Japanese fossil ranges were compiled from Aoki (1963), Saito (1963), Takayanagi and Saito (1962), and Ujiie and Kagawa (1963). Honshu sections range from latitude 33° to 40° north; southern California sections are located between latitudes 33° - 34° north.

California are limited to two horizons in the lower and upper Pliocene (Text-fig. 43). Moreover the oscillating subarctic, temperate, and subtropical biofacies in the marginal eastern Pacific offer a much clearer and decisive set of planktonic indices by which to analyze synchronous events during the late Miocene and Pliocene than the continuous tropical sequences in Honshu.

SUMMARY AND CONCLUSIONS

The Neogene marine sequence in southern California presents an ideal region in which to illustrate variation of biofacies and lithofacies across the Miocene-Pliocene boundary. Extensive tectonic adjustment during this period created a series of deep marine basins allowing a wide spectrum of marine environments to exist in close proximity.

Micropaleontologists have traditionally placed the Miocene-Pliocene boundary in California between the Delmontian and Repettian Stages. These stages are based on environmentally controlled benthic foraminiferal groups which are inherently time-transgressive. In some instances the Miocene-Pliocene boundary has been defined on the presence or absence of a single benthic foraminifer. Not surprisingly, vertebrate, invertebrate, and foraminiferal workers differ in their placement of this boundary. For example, the discrepancy between the Miocene-Pliocene boundary as defined on vertebrate paleontologic criteria and benthic foraminiferal criteria exceeds stage-age magnitude (Durham, Jahns, and Savage, 1954) as it does in Europe (Savage, 1955). Increased precision and availability of radiometric dating appear to offer the most rational solution to the fundamental problems of long range correlation and definition of unit boundaries. Consequently, the Miocene-Pliocene boundary was defined in this report as an isochronous surface at 10×10^6 years before the present. By definition, such a surface or time-plane must transgress lithofacies and biofacies (planktonic and benthic) boundaries in light of what is known about the present biologic and sedimentologic diversity within the marine environment. The specific purpose of this report is to demonstrate the vertical and horizontal variation of planktonic and benthic foraminiferal facies within sediments deposited during the late Miocene and Pliocene of southern California and to relate these variations to paleo-oceanographic and paleobathymetric changes.

A continuously fossiliferous surface section encompassing the Miocene-Pliocene boundary is not available. Consequently, several sequences of bathyal sediments exposed along the periphery of the Los Angeles and Ventura Basins were utilized to form a composite picture. Sections analyzed from the Los Angeles Basin included sequences exposed at Malaga Cove, the Repetto Hills, and Bunker Hill; a previous analysis of the Newport Mesa section was used to illustrate general planktonic trends. Sections analyzed from the Ventura Embayment included exposures at Woodland Hills, Mission Hills, and Balcom Canyon. In addition, planktonic faunas were analyzed from the Plio-Pleistocene San Diego Formation exposed at Pacific Beach.

Paleobathymetric and paleoecologic interpretations of the major sections utilized were based on analogy between the distributions of Recent and fossil benthic foraminiferal populations and sediment character. Quantitative faunal parameters recorded include foraminiferal number, planktonic-benthic ratio, species diversity, and radiolarian number. Benthic Foraminifera were organized into five faunal groups representative of shelf to lower bathyal depths with a sixth group created for species characteristic of low oxygen conditions within silled basins. Minimum percentage of displaced benthic species was determined by assuming elements of the deepest faunal group present in a given sample represented the indigenous fauna. Radiolarian facies were interpreted as indicative of lower bathyal environments analogous to modern biofacies within basins deeper than 2,500 meters in the Gulf of California. Increasing maximum diameter of spumellarians was also interpreted as a reflection of increasing depth.

The Malaga Cove section represents a series of upper Miocene through mid-Pliocene sediments deposited at lower to middle bathyal depths within the southwestern portion of the Los Angeles Basin. Three distinct lithofacies and benthic biofacies are represented within this sequence. Laminated diatomites of the Valmonte Diatomite were deposited on the subsiding floor of a silled basin characterized by oxygen values of less than 0.3 ml/l.; the effective basin sill was at 1,000-1,300 meters whereas the basin floor was at least 2,000-2,500 meters deep. Late Miocene tectonics destroyed the effective sill of the basin, aided subsidence, and allowed deposition of a radiolarian-rich foraminiferan-barren mudstone facies (Malaga Mudstone) at 3,000-3,500 meters. A K-Ar date of 9.9×10^6 years B.P. was obtained on a vitric ash within the upper portion of this facies indicating the Miocene-Pliocene boundary as defined in this report

occurs within a foraminiferan barren facies in this area. A disconformity brought about by late Miocene-early Pliocene uplift of a portion of the basin floor separates the radiolarian mudstone facies from an overlying unit composed of foraminiferan-rich glauconitic silt (Repetto Formation); large numbers of foraminiferal tests and glauconite pellets indicate a low rate of deposition. Displaced shelf species and pebbles of glaucophane schist indicate the upper portion of the isolated bottom prominence was within wave base by the mid-Pliocene. Dominant lower and middle bathyal species indicate deposition of this facies occurred at 2,000-2,500 meters on the flank of the structure.

The lower Pliocene Repetto Hills section consists of 1,350 meters of sandy siltstones (Repetto Formation) containing numerous graded sands and flow structures. A marginal lower bathyal fauna indicates these sediments were deposited near the base of the steep northeastern slope of the Los Angeles Basin at depths of 2,000-2,500 meters. Percentage of displaced upper bathyal species increases with time, indicating that the rate of sedimentation increased during the late early Pliocene. The Bunker Hill section nine km to the west also represents a portion of a lower to middle bathyal slope or possibly a submarine fan equivalent to the upper portion of the Repetto Hills section.

The Woodland Hills and Mission Hills sections represent upper Miocene and lower Pliocene bathyal sequences deposited in the southeastern portion of the east-west Ventura Embayment. The upper Miocene portion of the Woodland Hills section (Modelo Formation) is composed of massive deep-water turbidite sands (Tarzana Submarine Fan) and thin indigenous bathyal sediments including diatomaceous shales. Foraminiferal analysis indicated deposition of the coarse clastics took place at about 1,800 meters below sill depth in an impoverished basin. Laminated diatomites were accumulating on the basin floor to the northeast in the Mission Hills area at the same time sands were being vigorously deposited on the fan. During the late Miocene, tectonic adjustment of basin margins and subsidence of the basin plain caused cessation of deposition on the Tarzana Fan, allowing continuous accumulation of laminated diatomites that contained an impoverished benthic fauna dominated by *Bolivina rankini*. Late Miocene and early Pliocene structural activity again altered basin configuration, resulting in an increased rate of deposition and rapid shoaling accompanied by increased foraminiferal number and the successive appearance of middle and upper bathyal faunas. The uppermost portion of this section (Repetto

Formation) consists of fine sands with abundant megafossils and a sub-tropical benthic foraminiferal population indicative of shelf depths.

Qualitative analysis of benthic faunas in the Balcom Canyon section illustrates that these sediments were deposited at shelf to upper middle bathyal depths during the late Pliocene. Exposures of the Plio-Pleistocene San Diego Formation studied at Pacific Beach represent an outer shelf deposit.

Evaluation of variation in planktonic foraminiferal facies deposited during the late Miocene and Pliocene in southern California is based on the present asymmetric distribution of temperature-sensitive planktonic faunas in the North Pacific (Bradshaw, 1959; Parker, 1962; Smith, 1963, 1964). Analysis of modern planktonic biofacies in the marginal eastern Pacific reveals that southern California occupies a critical transition zone between areas dominated by subarctic and tropical assemblages. It is also apparent that the most important factor controlling the distribution of these faunas is the cool, equatorward California Current. Because this eastern boundary current has its origin at high latitudes it is characterized by high percentages of the boreal species *Globigerina bulloides* and *G. pachyderma*; sinistrally coiled specimens of *G. pachyderma* predominate north of latitude 45°. The zone of mixing between the California Current and warm equatorial waters is presently located at about latitude 25°; high percentages of *Globorotalia inflata* mark this zone along with increasing percentages of keeled globorotalids and various species of *Globigerinoides*. Analysis of variations of planktonic assemblages with depth indicates shelf areas lack a complete planktonic fauna, consequently the present study was confined to sediments deposited below 150 meters.

Analyses of mid-Miocene through Pleistocene planktonic assemblages in southern California illustrate that the California Current has maintained a temperate fauna in this area since the mid-Miocene. *Globigerina concinna* and *G. bulloides* were predominate during the late mid-Miocene whereas *G. bulloides* and *G. pachyderma* predominated during the late Miocene to Recent.

Specific investigation of late Miocene and Pliocene planktonic assemblages in the sections listed above revealed a number of important trends:

1. Lower upper Miocene faunas are characterized by rare occurrences of *Globorotalia mayeri*, diminishing percentages of *Globigerina concinna*, continuing abundance of *G. bulloides*, and the initial appearance of dextrally coiling specimens of *G. pachyderma*.

2. Middle upper Miocene faunas represent the intrusion of a subarctic fauna characterized by an abundance of *Globigerina bulloides* and sinistrally coiling specimens of *G. pachyderma*, infrequent occurrences of *Sphaeroidinellopsis seminulina*, *S. subdebiscens*, *Globigerina druryi decoraperta* and *Globorotaloides hexagonus*, and the initial appearance of *Globigerina eggeri*.

3. Uppermost Miocene assemblages reflect increasing surface temperature and contain an abundance of *Globigerina bulloides* and dextrally coiling specimens of *G. pachyderma*, rapidly increasing abundances of *G. eggeri*, and the final appearance of the radiolarian *Prunopyle titan*.

4. Lower Pliocene faunas are characterized by a subtropical fauna dominated by *Globigerina eggeri*, common to abundant specimens of *Globorotalia inflata*, dextral specimens of *Globigerina pachyderma*, and rare to common occurrences of *Globigerinella siphonifera*, *Globigerinoides conglobatus*, *G. ruber*, *G. trilobus sacculifer*, *G. trilobus trilobus*, *Globoquadriina conglomerata*, *Globorotalia crassaformis*, *G. menardi menardi*, *G. menardi tumida*, *Globorotaloides hexagonus*, *Pulleniatina obliquiloculata*, and "*Sphaeroidinella debiscens*."

5. The mid-Pliocene was marked by the reappearance of a subarctic fauna containing a large percentage of sinistrally coiling specimens of *Globigerina pachyderma* along with *Globigerina bulloides*.

6. Upper Pliocene assemblages reflect increasing water temperature and contain a high percentage of *Globigerina bulloides*, dextrally coiling specimens of *G. pachyderma*, and the initial occurrences of *Globorotalia truncatulinoides*. The latest Pliocene is marked by alternating zones of sinistral and dextral specimens of *Globigerina pachyderma* and a brief intrusion of a subtropical fauna containing *Globigerinoides conglobatus*, *Globorotalia menardi*, and other tropical taxa.

7. Pleistocene faunas are dominated by sinistrally coiling specimens of *Globigerina pachyderma* and an abundance of *Globigerina bulloides*.

The upper Miocene through Pleistocene planktonic sequence represents a series of oscillations of subarctic, temperate, and subtropical biofacies in response to variations in surface temperature. A total of nine planktonic zones can be recognized on the basis of predominant species. The boundaries of these zones together with the upper and lower limits of selected species provide 13 planktonic indices in strata deposited during the last 15×10^6 years. Thus the proposed planktonic scale has a precision of about $1\text{--}1.5 \times 10^6$ years. Analogy between fossil and modern planktonic

biofacies indicate surface temperature has varied from 10°C to 25°C during the late Miocene to Recent interval off southern California.

Appearances of subarctic planktonic assemblages in southern California are interpreted as evidence of periods of intense polar refrigeration during the late Miocene, mid-Pliocene, and Pleistocene. The 10°C isotherm was probably located 10°-15° south of its present position during these intervals. The arrival of a subtropical fauna in this area during the early Pliocene suggests the zone of mixing between the California Current and warm equatorial waters was located about 10° north of its present position during this interval. Thus the Miocene-Pliocene boundary in southern California is bracketed by periods of maximum and minimum surface temperature.

The gradual rise in surface temperature from latest Miocene to early Pliocene likely caused the staggered and delayed appearance of warm water species into southern California. It seems reasonable to assume that tropical planktonic morphotypes appeared earlier in low latitudes than in middle or high latitudes. An outstanding example of delay due to faunal migration is that of *Globorotalia truncatulinoides*. This species appeared in the earliest Pliocene in the tropical western Pacific, whereas it did not appear in the southern California region until the late Pliocene.

Planktonic zones and datum levels defined allow correlation of dissimilar paleobathymetries, benthic biofacies, and sedimentary regimes with the epicontinental sections analyzed. Furthermore, dissimilar events are correlated within the confines of a single basin and between widely separated basinal areas. Alignment of the radiometric and planktonic scales allows the relative rate of deposition of the various sections to be scrutinized. These planktonic correlations provide several examples of the time-transgressive nature of benthic faunas. For instance, Mohnian Stage faunas appear to have existed for a longer period in the Woodland Hills section of the Ventura Embayment than in the Palos Verdes area of the Los Angeles Basin. Wheelerian ("Upper Pliocene") and Hallian ("Lower Pleistocene") Stage faunas in the eastern Ventura Embayment are shown to have been deposited during the early Pliocene whereas the same paleobathymetric biofacies were deposited during the late Pliocene in the western portion of the embayment. Re-evaluation of basinal sequences in southern California in light of synchronous planktonic horizons will likely result in adjustment of previous interpretations of basin histories.

Comparison of the late Tertiary planktonic sequence in southern California with that described from the MOHOLE (Parker, 1962) reveals several common planktonic horizons. These synchronous horizons allow comparison of the thick, rapidly deposited epicontinental sequence with the thin, telescoped section on the adjacent deep-sea floor.

The late Tertiary record of subarctic, temperate, and subtropical planktonic biofacies delineated in southern California is the unique product of temperature oscillations in the mid-latitudes of the marginal eastern North Pacific. A continuously boreal fauna predominated in high latitudes during the same interval while a continuous tropical biofacies occurred in low latitudes. Nevertheless, the late Miocene-early Pliocene poleward shift of warm surface water marked by the incursion of a subtropical biofacies in southern California, can be detected as far north as latitude 47°. In fact, a generalized analysis of upper Tertiary planktonic biofacies in the marginal eastern Pacific illustrates that these biofacies form wedge-shaped latitudinal regressions and transgressions in time. During a warm phase, tropical, subtropical, and warm temperate planktonic species are successively eliminated as warm isotherms move poleward. Elimination of critical species such as "*Sphaeroidinella debiscens*" (Bandy, 1964b; Parker, 1965b) demonstrates that taxa commonly used to mark the Pliocene-Miocene boundary in tropical latitudes cannot be utilized in the high latitude areas of the eastern Pacific. Time is also involved in these oscillations; thus warm water species appear later in time at successively higher latitudes in the marginal eastern Pacific. However, periods of polar refrigeration cause an increase in speed of the California Current, an overall decrease in temperature, and the rapid appearance of subarctic faunas as far south as latitude 28°.

The difference between planktonic biofacies during the late Tertiary in the western and eastern Pacific is illustrated by comparison of the vertical ranges of planktonic species in Honshu, Japan, and southern California. It is strikingly clear that the warm, poleward, Kuroshio Current has maintained an exclusively tropical-subtropical planktonic biofacies in the marginal western Pacific during the past 15×10^6 years. In contrast at least five major latitudinal adjustments of planktonic biofacies occurred during the same period in the marginal eastern North Pacific due to the sympathetic relationship between physical events in the Arctic and character of the California Current. Discrepancies between the planktonic sequences in the marginal western and eastern Pacific dictate caution should be used in randomly projecting planktonic data within the North Pacific Basin.

It would seem more worthwhile to concentrate on correlation of inferred paleo-oceanographic trends rather than specific planktonic horizons in order to construct a logical picture of variations in surface temperature and current character within a given ocean basin.

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FAUNAL REFERENCE LIST

Listed below are references to the original description of each species of Foraminifera and Radiolaria mentioned in the text. All trinominals represent genus, species, and subspecies. Preferred modern names are followed by the original designation and reference.

FORAMINIFERA

PLANKTONIC SPECIES

- Globigerina bulloides bulloides* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 277; Modèles, No. 76.
- Globigerina bulloides quadrilatera* Galloway and Wissler = *Globigerina quadrilatera* Galloway and Wissler, 1927, Jour. Paleont. vol. 1, No. 1, pp. 44, 84, pl. 7, fig. 11.
- Globigerina concinna* Reuss, 1850, K. Akad. Wiss. Wien, Denkschr., Math.-Nat. Kl., vol. 1, p. 373, pl. 47, fig. 8.
- Globigerina eggeri eggeri* Rumbler, 1901, *Foraminiferen*, in Brandt, *Nordisches Plankton*, pt. 1, No. 14, pp. 19-20, text-fig. 20. All specimens not possessing a high spire and five to six globular chambers in the final whorl as the type of this species were considered variants. Within large populations variants with four chambers in the final whorl and a flat spire generally predominated over those resembling the type figure. Teeth were absent from all specimens of this species. Absence of teeth is apparently a characteristic of those individuals within temperate to warm temperate latitudes contrary to specimens found at low latitudes (see Parker, 1962).
- Globigerina druryi decoraperta* Takayanagi and Saito, 1962, Tohoku Univ., Science Rpts., Sec. Ser. (Geology), Spec. vol., No. 5, p. 85, pl. 28, figs. 10a-c.
- Globigerina pachyderma* (Ehrenberg) = *Aristerospira pachyderma* Ehrenberg, 1861, K. Akad. Wiss. Berlin, Monatsber., pp. 276-277, 303; 1873, pl. 1, fig. 4.
- Globigerina quinqueloba* Natland, 1938, Scripps Inst. Oceanogr., Bull., Tech. Serv., vol. 4, No. 5, p. 149, pl. 6, fig. 7.
- Globigerinella siphonifera* (d'Orbigny) = *Globigerina siphonifera* d'Orbigny, 1839, *Foraminifères*, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, p. 83, pl. 4, figs. 15-18.
- Globigerinita glutinata* (Egger) = *Globigerina glutinata* Egger, 1895, K. Bayer, Akad. Wiss., Math.-Phys. Kl., Abh., vol. 18, pt. 2, p. 371, pl. 13, figs. 19-21.
- Globigerinita humilus* (Brady) = *Truncatulina humilus* Brady, 1884, Rept. Voy. Challenger, vol. 9, p. 665, pl. 94, fig. 7.
- Globigerinita uvula* (Ehrenberg) = *Pyrodexia uvula* Ehrenberg, 1861, K. Preuss, Akad. Wiss. Berlin, Monatsber., pp. 276, 277, 308.
- Globigerinoides conglobatus* (Brady) = *Globigerina conglobata* Brady, 1879, Quart. Jour. Micr. Sci., n. ser., vol. 19, p. 286.
- Globigerinoides ruber* (d'Orbigny) = *Globigerina rubra* d'Orbigny, 1838, *Foraminifères*, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, p. 82, pl. 4, figs. 12-14. Because of the great variations in morphology exhibited by this species in recent populations (Parker, 1962), forms commonly referred to *G. cyclostomus* and *G. elongatus* were included within *G. ruber*.
- Globigerinoides trilobus sacculifer* (Brady) = *Globigerina sacculifera* Brady, 1877, Geol. Mag., n. ser., dec. 2, vol. 4, No. 12, p. 535.
- Globigerinoides trilobus trilobus* (Reuss) = *Globigerina triloba* Reuss, 1850, K. Akad. Wiss. Wien., Math.-Nat. Kl. Denkschr., vol. 1, p. 374, pl. 47, fig. 11.
- Globigerinoides trilobus immaturus* (LeRoy) = *Globigerinoides sacculiferus* Brady var. *immatura* LeRoy, 1941, Colorado Sch. Mines, Quart., vol. 36, No. 1, p. 44, pl. 1, figs. 37-39.

- Globoquadrina conglomerata* (Schwager) = *Globigerina conglomerata* Schwager, 1866, Novara-Exped., Geol., vol. 2, pt. 2, p. 255, pl. 7, fig. 113.
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- Globorotalia hirsuta* (d'Orbigny) = *Rotalina hirsuta* d'Orbigny, 1839, *Foraminifères*, in Barker-Webb and Berthelot, Hist. Nat. Iles Canares, vol. 2, pt. 2, p. 131, pl. 1, figs. 37-39.
- Globorotalia inflata* (d'Orbigny) = *Globigerina inflata* d'Orbigny, 1839, *Foraminifères*, in Barker-Webb and Berthelot, Hist. Nat. Iles Canares, vol. 2, pt. 2, p. 134, pl. 2, figs. 7-9.
- Globorotalia mayeri* Cushman and Ellisor, 1939, Cushman Lab. Foram. Res. Contr., vol. 15, pt. 1, p. 11, pl. 2, fig. 4.
- Globorotalia menardi menardi* (d'Orbigny) = *Rotalia menardi* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 273; Modèles No. 10.
- Globorotalia menardi tumida* (Brady) = *Pulvinulina menardi tumida* Brady, 1877, Geol. Mag., n. ser., dec. 2, vol. 4, No. 12, p. 535.
- Globorotalia scitula* (Brady) = *Pulvinulina scitula* Brady, 1882, Roy. Soc. Edinburgh, Proc., vol. 11, p. 716.
- Globorotalia truncatulinoides* (d'Orbigny) = *Rotalina truncatulinoides* d'Orbigny, 1839, *Foraminifères*, in Barker-Webb and Berthelot, Hist. Nat. Iles Canares, vol. 2, pt. 2, p. 132, pl. 2, figs. 25-27.
- Globorotaloides hexagonus* (Natland) = *Globigerina hexagona* Natland, 1938, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 4, No. 5, p. 149, pl. 7, fig. 1.
- "*Orbulina*" chambers—Recent studies of living and fossil tests formerly assigned to the species "*Orbulina universa*" have revealed these tests to be reproductive (?) chambers of several species; it appears the majority of orbulinid tests occurring within the temperate latitudes of the eastern Pacific represent a reproductive stage in the life cycle of *Globigerina bulloides* (Bandy, 1966; Bandy, Ingle, and Frerichs, 1965; P. A. Adshead, personal communication, 1965).
- Pulleniatina obliquiloculata* (Parker and Jones) = *Pullenia sphaeroides obliquiloculata* Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., vol. 155, pp. 365, 368, pl. 19, fig. 4.
- "*Sphaeroidinella debiscens*" (Parker and Jones) = *Sphaeroidina bulloides debiscens* Parker and Jones 1865, Roy. Soc. London, Philos. Trans., vol. 155, p. 369, pl. 19, fig. 5. Recent studies have illustrated that this "species" is a morphotypic derivative of several tropical planktonic species principally *Globigerinoides trilobus trilobus* and *Globigerinoides trilobus sacculifer* (Bé, 1965; Bandy, Ingle, and Frerichs, 1965).
- Sphaeroidinellopsis subdebiscens* = *Sphaeroidinella debiscens subdebiscens* Blow, 1959, Bull. Amer. Paleont., vol. 39, No. 178, p. 195, pl. 12, figs. 71-72.
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- Angulogerina angulosa* (Williamson) = *Uvigerina angulosa* Williamson, 1858, Recent Foram. Gt. Britain, Ray Soc., p. 67, pl. 5, fig. 140.
- Angulogerina baggi* (Galloway and Wissler) = *Uvigerina baggi* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, p. 75, pl. 11, fig. 19.
- Angulogerina carinata* Cushman, 1927, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 1, No. 10, p. 159, pl. 4, fig. 3.

- Angulogerina hughesi picta* Todd, 1948, Allan Hancock Pacific Exped., vol. 6, No. 5, pp. 290-291, pl. 36, fig. 3.
- Angulogerina occidentalis* (Cushman) = *Uvigerina occidentalis* Cushman, 1923, U.S. Nat. Mus., Bull. 104, pt. 4, p. 169, pl. 5, figs. 3-4.
- Baggina californica* Cushman, 1926, Cushman Lab. Foram. Res., Contr., vol. 2, pt. 3, p. 64, pl. 9, fig. 8.
- Bolivina acuminata* Natland = *Bolivina subadvena* Cushman var. *acuminata* Natland, 1946, in Cushman and Gray, Cushman Lab. Foram. Res., Spec. Publ., No. 19, p. 34, pl. 5, fig. 46.
- Bolivina acutula* Bandy = *Bolivina advena* Cushman var. *acutula* Bandy, 1953, Jour. Paleont., vol. 27, No. 2, p. 180, pl. 24, fig. 7.
- Bolivina advena* Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 2, p. 29, pl. 5, fig. 1.
- Bolivina argentea* Cushman 1926, Cushman Lab. Foram. Res., Contr., vol. 2, pt. 2, p. 42, pl. 6, fig. 5.
- Bolivina benedictensis* Pierce, 1956, Jour. Paleont., vol. 30, No. 6, p. 1,307, pl. 142, fig. 9 (= "*Bolivina hughesi*" of many authors).
- Bolivina bramlettei* Kleinpell 1938, *Miocene stratigraphy of California*, Amer. Assoc. Petrol. Geol., p. 326, pl. 13, fig. 2.
- Bolivina advena* Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 2, pp. 31-32, pl. 5, fig. 8.
- Bolivina decurtata* Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 2, pt. 2, p. 44, pl. 6, fig. 7.
- Bolivina girardensis* Rankin, 1934, in Cushman and Kleinpell, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 17, pl. 3, fig. 7.
- Bolivina granti* Rankin, 1934, in Cushman and Kleinpell, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 21, pl. 4, figs. 2-3.
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- Bolivina interjuncta* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, No. 1, p. 70, pl. 11, figs. 10-13.
- Bolivina marginata marginata* Cushman, 1918, U.S. Geol. Sur., Bull., No. 676, p. 48, pl. 10, fig. 1.
- Bolivina marginata multicostata* (Cushman) = *Bolivina aenariensis* (Costa) var. *multicostata* Cushman, 1918, U.S. Geol. Sur., Bull., No. 676, p. 48, pl. 10, fig. 2.
- Bolivina pacifica* Cushman and McCulloch = *Bolivina acerosa* Cushman and McCulloch, 1942, Allan Hancock Pacific Exped., vol. 6, No. 4, p. 185, pl. 21, figs. 2-3.
- Bolivina plicata* d'Orbigny, 1839, *Voy. Amér. Méri.*, *Foraminifères*, vol. 5, p. 62, pl. 8, figs. 4-7.
- Bolivina plicatella* Cushman, 1930, Florida State Geol. Sur., Bull., No. 4, p. 46, pl. 8, fig. 10.
- Bolivina pseudoplicata* Heron-Allen and Earland, 1930, Jour. Roy. Micr. Soc., vol. 50, p. 81, pl. 3, figs. 36-40.
- Bolivina pseudospissa* Kleinpell, 1938, *Miocene stratigraphy of California*, Amer. Assoc. Petrol. Geol., p. 279, pl. 21, fig. 6.
- Bolivina rankini* Kleinpell, 1938, *Miocene stratigraphy of California*, Amer. Assoc. Petrol. Geol., p. 280, pl. 22, figs. 4, 9.
- Bolivina seminuda foraminata* R. E. and K. C. Stewart, 1930, Jour. Paleont. vol. 4, No. 1, p. 66, pl. 8, fig. 5.
- Bolivina seminuda humilis* Cushman and McCulloch, 1942, Allan Hancock Pacific Exped., vol. 6, p. 211, pl. 26, figs. 1-6.
- Bolivina seminuda seminuda* Cushman, 1911, U.S. Nat. Mus., Bull. 71, p. 34, text-fig. 55.
- Bolivina obliqua* Barbat and Johnston, 1934, Jour. Paleont., vol. 8, No. 1, p. 15, pl. 1, fig. 20.

- Bolivina semiperforata* Martin, 1952, Cushman Lab. Foram. Res., Contr., vol. 3, pts. 3-4, p. 129, pl. 21, figs. 10-11.
- Bolivina sinuata* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, No. 1, pp. 71-72, pl. 11, fig. 9.
- Bolivina spissa* Cushman = *Bolivina subadvena* Cushman var. *spissa* Cushman, 1926, Cushman Lab. Foram. Res., Contr., vol. 2, pt. 2, p. 45, pl. 11, fig. 9.
- Bolivina subadvena subadvena* Cushman, 1926, Cushman Lab. Foram. Res., Contr., vol. 2, pt. 2, p. 44, pl. 6, fig. 6.
- Bolivina subadvena sulphurensis* Cushman and Adams, 1935, Cushman Lab. Foram. Res., Contr., vol. 11, pt. 1, p. 20, pl. 3, figs. 8-9.
- Bolivina tongi filicostata* Cushman and McCulloch, 1942, Allan Hancock Pacific Exped., vol. 6, No. 4, p. 214, pl. 27, figs. 7-11.
- Bolivina torquata* Cushman and McCulloch, 1942, Allan Hancock Pacific Exped., vol. 6, No. 4, p. 215, pl. 27, figs. 5-6.
- Bolivina vaughani* Natland, 1938, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 4, No. 5, p. 146, pl. 5, fig. 11.
- Bolivina woodringi* Kleinpell 1938, *Miocene Stratigraphy of California*, Amer. Assoc. Petrol. Geol., pp. 285-286, pl. 21, figs. 4-5.
- Bolivina minuta* (Natland) = *Bolivina minuta* Natland, 1938, Univ. California, Scripps Inst. Oceanogr. Bull., Tech. Ser., vol. 4, p. 146, pl. 5, fig. 10.
- Bolivinita quadrilatera* = *Textilaria quadrilatera* Schwager, 1866, Fossile Foraminiferen von Kar Nikobar, Novara Exped., Wien, Österreich Geol. Theil., Bd. 2, Abt. 2, p. 253, pl. 7, fig. 103.
- Buccella frigida* (Cushman) = *Pulvinulina frigida* Cushman, 1922, Canadian Biol., Contr., p. 12.
- Buccella tenerima* (Bandy) = *Rotalia tenerima* Bandy, 1950, Jour. Paleont., vol. 24, No. 3, p. 278, pl. 24, fig. 3.
- Bulimina affinis* d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, *Foraminifères*, p. 105, pl. 2, figs. 25-26.
- Bulimina marginata denudata* Cushman and Parker = *Bulimina pagoda* Cushman var. *denudata* Cushman and Parker, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, pt. 3, p. 57, pl. 10, figs. 1-2.
- Bulimina pagoda hebespinata* R. E. and K. C. Stewart 1930, Jour. Paleont., vol. 4, No. 1, p. 63, pl. 8, fig. 3.
- Bulimina pagoda pagoda* Cushman, 1927, California, Univ., Scripps Inst. Oceanogr. Bull., Tech. Ser., vol. 1, p. 152, pl. 2, fig. 16.
- Bulimina rostrata* H. B. Brady, 1884, Rept. Voy. *Challenger*, Zool., vol. 9, p. 408, pl. 51, figs. 14-15.
- Bulimina striata mexicana* Cushman = *Bulimina inflata* Sequenza var. *mexicana* Cushman, 1922, U.S. Nat. Mus., Bull. 104, pt. 3, p. 95, pl. 21, fig. 2.
- Bulimina subacuminata* Cushman and K. C. Stewart, 1930, San Diego Soc. Nat. Hist., Trans., vol. 6, p. 65, pl. 5, figs. 2-3.
- Bulimina subcalva* Cushman and K. C. Stewart, 1930, San Diego Soc. Nat. Hist. Trans., vol. 6, p. 65, pl. 4, fig. 11.
- Buliminella brevior* Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, No. 8, p. 33, pl. 5, fig. 14.
- Buliminella curta* Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, No. 8, p. 33, pl. 5, fig. 13.
- Buliminella curta basispinata* Cushman 1930, Jour. Paleont., vol. 4, No. 1, p. 63, pl. 8, fig. 6.
- Buliminella ecuadorana* Cushman and Stevenson, 1948, Cushman Lab. Foram. Res., Contr., vol. 24, pt. 3, p. 57, pl. 9, figs. 19-20.
- Buliminella elegantissima* (d'Orbigny) = *Bulimina elegantissima* d'Orbigny, 1939, *Voy. Amer. Merid., Foraminifères*, vol. 5, pt. 5, p. 51, pl. 7, figs. 13-14.

- Buliminella exilis tenuata* Cushman = *Buliminella subfusiformis* Cushman var. *tenuata* Cushman, 1927, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 1, p. 149, pl. 2, fig. 9.
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- Cancris auricula* (Fichtel and Moll) = *Nautilus auricula* Fichtel and Moll, 1798, *Testacea microscopa*, 1798, p. 108, pl. 20, figs. a-c.
- Cassidella bramlettei* (Galloway and Morrey) = *Virgulina bramlettei*, 1929, Bull. Amer. Paleont., vol. 15, No. 55, p. 37, pl. 5, fig. 14.
- Cassidella californiensis* (Cushman) = *Virgulina californiensis* Cushman, 1925, Cushman Lab. Foram. Res., Contr., pt. 2, vol. 1, p. 32, pl. 5, fig. 11.
- Cassidella pontoni* (Cushman) = *Virgulina pontoni* Cushman, 1932, Jour. Paleont., vol. 8, pt. 1, No. 118, p. 17, pl. 3, fig. 7.
- Cassidella seminuda* (Natland) = *Virgulina semniuda* Natland, 1938, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 4, p. 145, pl. 5, fig. 12.
- Cassidulina barbarana* Cushman and Kleinpell, 1934, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 16, pl. 3, fig. 5.
- Cassidulina californica* Cushman and Hughes, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, No. 6, p. 12, pl. 2, fig. 1.
- Cassidulina crassa* d'Orbigny 1839, *Voy. Amer. Merid., Foraminifères*, vol. 5, pt. 5, p. 56, pl. 7, figs. 18-20.
- Cassidulina cushmani* R. E. and K. C. Stewart, 1930, Jour. Paleont., vol. 4, No. 1, p. 71, pl. 9, fig. 5.
- Cassidulina delicata* Cushman, 1927, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 1, p. 168, pl. 6, fig. 5.
- Cassidulina laevigata carinata* Cushman, 1931, Cushman Lab. Foram. Res., Contr., vol. 7, pt. 1, pp. 14-15, pl. 2, fig. 14.
- Cassidulina limbata* Cushman and Hughes, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 1, p. 12, pl. 2, fig. 2.
- Cassidulina lomitensis* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, No. 1, p. 79, pl. 12, fig. 10.
- Cassidulina minuta* Cushman, 1933, Cushman Lab. Foram. Res., Contr., vol. 9, pt. 4, p. 92, pl. 10, fig. 3.
- Cassidulina modeloensis* Rankin, 1934, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 23, pl. 3, fig. 12.
- Cassidulina panzana* Kleinpell, 1938, *Miocene Stratigraphy of California*, Amer. Assoc. Petrol. Geol., p. 335, pl. 8, fig. 9.
- Cassidulina sublobosa quadrata* Cushman and Hughes, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 1, p. 15, pl. 2, fig. 7.
- Cassidulina sublobosa subglobosa* Brady, 1881, Quart. Jour. Micr. Sci., new ser., vol. 21, p. 60.
- Cassidulina tortuosa* Cushman and Hughes, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 1, p. 14, pl. 2, fig. 4.
- Cassidulina translucens* Cushman and Hughes, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 1, p. 15, pl. 2, fig. 5.
- Cassidulinoides cornuta* (Cushman) = *Virgulina cornuta* Cushman, 1913, U.S. Nat. Mus., Proc., vol. 44, p. 637, pl. 80, fig. 1.
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- Chilostomella ovoidae* Reuss, 1850, K. Akad. Wiss. Wien, Math.-Nat. Kl., Denkschr., Wien, Österreich, 1850, Bd. 1, p. 380, pl. 48, fig. 12.
- Cibicides fletcheri* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, No. 1, p. 64, pl. 10, figs. 8-9.
- Cibicides lobatus* (Montagu) = *Serpula lobata* Montagu, 1803, Test. Brit., pp. 515-516.

- Cibicides mckannai* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, No. 1, p. 65, pl. 10, fig. 5.
- Cibicides spiralis* Natland, 1938, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 4, No. 5, p. 151, pl. 7, fig. 7.
- Dentalina baggi* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, No. 1, p. 49, pl. 8, figs. 14-15.
- Dentalina decepta* (Bagg) = *Nodosaria decepta* Bagg, 1912, U.S. Geol. Sur., Bull., No. 513, p. 55, pl. 16, fig. 1.
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- Discorbinella valmonteensis* Kleinpell, 1938, *Miocene stratigraphy of California*, Amer. Assoc. Petrol. Geol., pp. 350-351, pl. 21, figs. 14-15.
- Dyocibicides biserialis* Cushman and Valentine, 1930, Stanford Univ., Contr., Dept. Geol., vol. 1, No. 1, pl. 10, figs. 1-2.
- Elphidiella hannaï* (Cushman and Grant) = *Elphidium hannaï* Cushman and Grant, 1927, San Diego Soc. Nat. Hist. Trans., vol. 5, No. 6, p. 77, pl. 8, figs. 1-2.
- Elphidium articulatum* (d'Orbigny) = *Polystomella articulata* d'Orbigny, 1839, *Voy. Amer. Merid., Foraminifères*, vol. 5, pt. 5, p. 30, pl. 3, figs. 9-10.
- Elphidium crispum* (Linné) = *Nautilus crispus* Linné, 1758, *Systema Naturae*, ed. 10, p. 709.
- Elphidium hughesi* Cushman and Grant, 1927, San Diego Soc. Nat. Hist., Trans., vol. 5, No. 6, p. 75, pl. 7, fig. 1.
- Elphidium incertum* (Williamson) = *Polystomella umbilicatulæ* (Walker) var. *incerta* Williamson 1858, Roy. Soc., London, p. 44, pl. 3, fig. 82a.
- Elphidium poeyanum translucens* Natland = *Elphidium translucens* Natland, 1938, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 4, No. 5, p. 144, pl. 5, figs. 3-4.
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- Ehrenbergina spinea*, 1935, Smithsonian Inst., Misc. Coll., vol. 91, No. 21, p. 8, pl. 3, figs. 10-11.
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- Epistominella evax* Bandy, 1953, Jour. Paleont., vol. 27, No. 2, p. 179, pl. 23, figs. 1 a-c.
- Epistominella exigua* (Brady) = *Pulvinulina exigua* Brady, 1884, Rept. Voy. Challenger, Zool., vol. 9, p. 696, pl. 103, figs. 13-14.
- Epistominella levicula* Resig, 1958, Micropaleont., vol. 4, No. 3, p. 304, text-fig. 16.
- Epistominella pacifica smithi* (R. E. and K. C. Stewart) = *Pulvinulinella smithi* R. E. and K. C. Stewart, 1930, Jour. Paleont., vol. 4, No. 1, p. 70, pl. 9, fig. 42-c.
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- Glandulina laevigata* d'Orbigny, 1826, Ann. Sci. Nat. vol. 7, p. 252, pl. 10, figs. 1-3.
- Glandulina tenuistriata*=*Pseudoglandulina tenuistriata* Bermudez, 1949, Cushman Lab. Foram. Res., Spec. Pub. No. 25, p. 163, pl. 10, fig. 45.
- Globobulimina marginospinata* (Cushman and Parker)=*Bulimina marginospinata* Cushman and Parker, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, pt. 3, p. 57, pl. 9, fig. 11.
- Globobulimina ovula ovula* d'Orbigny, 1839, Voy. Amer. Merid. Foraminifères, vol. 5, pt. 5, p. 51, pl. 1, figs. 10-11.
- Globobulimina ovula pedroana* (Kleinpell)=*Bulimina ovula* d'Orbigny var. *pedroana* Kleinpell, 1938, Miocene stratigraphy of California, Amer. Assoc. Petrol. Geol., p. 257, pl. 22, fig. 13.
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- Globobulimina pseudoaffinis*=*Bulimina pseudoaffinis* Kleinpell, 1938, Miocene Stratigraphy of California, Amer. Assoc. Petrol. Geol., p. 257, pl. 9, fig. 9.
- Globobulimina pyrula* (d'Orbigny)=*Bulimina pyrula*, 1846, Foraminifères fossiles du bassin tertiaire de Vienne. Gide et Comp., Paris, p. 184, pl. 11, figs. 9-10.
- Goesella flinti* Cushman, 1936, Cushman Lab. Foram. Res., Spec. Pub. 6, p. 34, pl. 5, fig. 8.
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- Gyroidina attiformis* R. E. and K. C. Stewart, 1930, Jour. Paleont. vol. 4, No. 1, p. 67, pl. 9, figs. 2 a-c.
- Gyroidina gemma* Bandy, 1953, Jour. Paleont., vol. 27, No. 2, p. 179, pl. 23, fig. 4.
- Gyroidina keenani* (Cushman and Kleinpell)=*Eponides keenani* Cushman and Kleinpell, 1934, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 14, pl. 3, figs. 10-11.
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- Gyroidina multilocula* (Coryell and Mossman)=*Gyroidina soldani* d'Orbigny var. *multilocula* Coryell and Mossman, 1942, Jour. Paleont., vol. 16, p. 237, pl. 36, fig. 20.
- Gyroidina rotundimargo* (R. E. and K. C. Stewart)=*Gyroidina soldani* d'Orbigny var. *rotundimargo* R. E. and K. C. Stewart, 1930, Jour. Paleont., vol. 4, p. 58, pl. 9, fig. 3.
- Gyroidina subtener* (Galloway and Wissler)=*Rotalia subtener* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, p. 60, pl. 10, fig. 4.
- Hanzawaia nitidula* (Bandy)=*Cibicidina basiloba* (Cushman) var. *nitidula* Bandy, 1953, Jour. Paleont., vol. 27, No. 2, p. 178, pl. 22, fig. 3.
- Haplophragmoides columbiense* Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 2, p. 39, pl. 6, fig. 2.
- Hoeglundina elegans* (d'Orbigny)=*Rotalia elegans* d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, p. 276. Modèles, No. 54.
- Karrerella milleri* Natland, 1938, Univ. California, Scripps Inst. Oceanogr. Bull. Tech. Ser., vol. 4, No. 5, p. 140, pl. 3, figs. 11-12.
- Lagena acuticosta* Reuss, 1861, Sitz. Akad. Wiss. Wien, vol. 44, pt. 1, p. 305, pl. 1, fig. 4.
- Lagena alocki* White, 1956, Jour. Paleont., vol. 30, No. 2, p. 246, pl. 27, fig. 7a, b.
- Lagena amphora* Reuss, 1863, K. Akad. Wiss. Wien, Math-Nat. Kl. Stizber., Bd. 46, Abth. 1 (1862), p. 330, pl. 4, fig. 57.
- Lagena costata* (Williamson)=*Entosolenia costata* Williamson, 1858, Roy Soc., London, pl. 1, fig. 18.
- Lagena elongata*=*Miliola elongata* Ehrenberg, 1884, Bericht Preuss. Akad. Wiss., Berlin, p. 274.

- Lagena hexagona*=*Entosolenia squamosa* (Montagu) var. *hexagona* Williamson, 1848, Ann. Mag. Nat. Hist., ser. 2, vol. 1, p. 20, pl. 2, fig. 23.
- Lagena hispida* Reuss, 1863, K. Akad. Wiss. Wien, Math.-Nat. Kl. Sitzber., Bd. 46, Abth. 1 (1862), p. 335, pl. 6, figs. 77-79.
- Lagena perlucida* (Montagu)=*Vermiculum perlucidum* Montagu, 1803, Testacea Brit., p. 525, pl. 14, fig. 3.
- Lagena scalariformis* (Williamson)=*Entosolenia squamosa* (Montagu) var. *scalariformis* Williamson, 1848, Ann. Mag. Nat. Hist., ser. 2, vol. 1, p. 20, pl. 2, figs. 21-22.
- Lagena striata* (d'Orbigny)=*Oolina striata* d'Orbigny, 1839, Voy. Amer. Merid., Foraminifères, vol. 5, pt. 5, p. 21, pl. 5, fig. 12.
- Lagena striatopunctata* (Parker and Jones)=*Lagena sulcata* Walker and Jacob var. *striatopunctata* Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., vol. 155, p. 350, pl. 13, figs. 25-27.
- Lagena sulcata laevicostata* Walker and Jacob, 1946, Cushman Lab. Foram. Res., Contr., vol. 22, pt. 2, p. 68, pl. 12, figs. 13-14.
- Lagena sulcata peculiaris* Cushman and McCulloch, 1950, Allan Hancock Pacific Exped., vol. 6, No. 6, pp. 361-362, pl. 48, figs. 11-13.
- Lagena sulcata sulcata* (Walker and Jacob)=*Serpula (Lagena) sulcata* Walker and Jacob, 1798, in Kanmacher, F., *Adam's Essays on the microscope*, Ed. 2, London, p. 634, pl. 14, fig. 5.
- Lagena williamsoni* (Aloek)=*Entosolenia williamsoni* Aloek, 1865, Proc. Lit. Philos. Soc., vol. 4, p. 193.
- Laticarinata pauperata* (Parker and Jones)=*Pulvinulina repanda* (Fichtel and Moll) var. *menardi* (d'Orbigny) subvar. *pauperata* Parker and Jones, 1965, Roy. Soc. London, Philos. Trans., vol. 155, p. 395, pl. 16, figs. 50-51.
- Loxostomum instabile* Cushman and McCulloch, 1942, Allan Hancock Pacific Exped., vol. 6, No. 4, p. 221, pl. 27, figs. 15-17, pl. 28, figs. 1-7.
- Loxostomum pseudobeyrichi* (Cushman)=*Bolivina pseudobeyrichi* Cushman, 1926, Univ. California, Scripps Inst. Oceanogr. Bull., Tech. Ser., vol. 1, p. 156, pl. 3, fig. 7.
- Marginulinopsis capistranoensis* White, 1956, Jour. Paleont., vol. 30, No. 2, pp. 246-247, pl. 27, figs. 2 a-c, 3 a-c, 6.
- Martinottiella communis*=*Clavulina communis* d'Orbigny, 1846, Foraminifères fossiles du bassin tertiaire de Vienne. Gide et comp., p. 196, pl. 12, figs. 1-2.
- Melonis barleeana* (Williamson)=*Nonionina barleeana* Williamson, 1858, Recent foram. Gt. Britain, Roy. Soc., p. 32, pl. 3, figs. 68-69.
- Melonis pompilioides* (Fichtel and Moll)=*Nautilus pompilioides* Fichtel and Moll, 1798, Testacea microscopia, p. 31, pl. 2, figs. 2-c.
- Nodosaria longiscata* d'Orbigny, 1846, Foraminifères fossiles du bassin tertiaire de Vienne. Gide et comp., p. 32, pl. 1, figs. 10-12.
- Nodosaria parexilis* Cushman and K. C. Stewart, 1930, San Diego Soc. Nat. Hist., Trans., vol. 6, p. 55, pl. 2, figs. 13-15.
- Nodosaria tympanipectiformis* Schwager, 1866, Novara Exped., Geol. Theil., vol. 2, pl. 5, fig. 34.
- Nonion belvidgensis* Barbat and Johnson, 1934, Jour. Paleont., vol. 8, No. 1, p. 11, pl. 1, figs. 8-9.
- Nonion labradoricus* Cushman and Kleinpell, 1934, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 4, pl. 1, figs. 8 a-b.
- Nonion goudkoffi* Kleinpell, 1938, Miocene stratigraphy of California, Amer. Assoc. Petrol. Geol., p. 231, pl. 20, figs. 2, 5.
- Nonionella basispinata* (Cushman and Moyer)=*Nonion pizarrensis* Berry var. *basispinata* Cushman and Moyer, 1930, Cushman Lab. Foram. Res., Contr., vol. 6, p. 54, pl. 7, fig. 18.
- Nonionella davananensis* Pierce, 1956, Jour. Paleont., vol. 30, No. 6, p. 1,303, pl. 137, fig. 10.

- Nonionella miocenica stella* Cushman and Moyer, 1930, Cushman Lab. Foram. Res., Contr., vol. 6, p. 56, pl. 7, figs. 17 a-c.
- Oridorsalis (Eponides) tener* (Brady) = *Truncatulina tener* Brady, 1884, Rept. Voy. Challenger, Zool., vol. 7, p. 655, pl. 95, fig. 11 a-c.
- Planulina ariminensis* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 280, pl. 14, figs. 1-3; Modèles, No. 49.
- Planulina ornata* (d'Orbigny) = *Truncatulina ornata* d'Orbigny, 1839, Voy. Amér. Mèrid. Foraminifères, vol. 5, pt. 5, p. 40, pl. 6, figs. 7-9.
- Plectofrondicularia advena* (Cushman) = *Frondicularia advena* Cushman, 1923, U.S. Nat. Mus., Bull. 104, p. 141, pl. 20, figs. 1-2.
- Plectofrondicularia californica* Cushman and R. E. Stewart, 1926, Cushman Lab. Foram. Res., Contr., vol. 2, p. 39, pl. 6, figs. 9-11.
- Pullenia bulloides* (d'Orbigny) = *Nonionina bulloides* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 293.
- Pullenia malkinae* Coryell and Mossman, 1942, Jour. Paleont., vol. 16, No. 2, p. 234, pl. 36, figs. 3-4.
- Pullenia salisburyi* Stewart and Stewart, 1930, Jour. Paleont., vol. 4, No. 1, p. 72, pl. 8, fig. 2.
- Pyrgo inornata* (d'Orbigny) = *Biloculina inornata* d'Orbigny, 1846, Foraminifères fossiles du bassin tertiaire de Vienne. Gide et comp., Paris, 1846, p. 266, pl. 16, figs. 7-9.
- Pyrgo laevis* DeFrance, 1824, Mollusques vers et zoophytes. In Dictionnaire des Sciences Naturelles, tome 32, p. 273, pl. 88, fig. 2.
- Quinqueloculina akneriana* d'Orbigny, 1846, Foraminifères fossiles du bassin tertiaire de Vienne. Gide et comp., p. 290, pl. 18, figs. 16-21.
- Quinqueloculina angulostriata* Cushman and Valentine, 1930, Stanford Univ., Dept., Geol., Contr., vol. 1, No. 1, p. 12, pl. 2, fig. 5.
- Quinqueloculina costata* d'Orbigny, 1826, Ann. Sci. Nat., vol. 7, No. 3, p. 301.
- Quinqueloculina lamarckiana* d'Orbigny, 1839, In De la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 189, pl. 11, figs. 14-15.
- Robulus cushmani* Galloway and Wissler, 1927, Jour. Paleont., vol. 1, No. 1, p. 51, pl. 8, fig. 11.
- Robulus mohrensis* Kleinpell, 1938, Miocene stratigraphy of California. Amer. Assoc. Petrol. Geol., p. 200, pl. 18, figs. 1-2.
- Robulus orbicularis* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 288, pl. 15, figs. 8-9.
- Robulus strongi* Church, 1929, Jour. Paleont., vol. 3, No. p. 305, text-fig. 3.
- Rotorbinella (?) garveyensis* (Natland) = *Rotalia garveyensis* Natland, 1938, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 4, No. 5, p. 147, pl. 6, fig. 6.
- Rotorbinella lomaensis* (Bandy) = *Rotalia lomaensis* Bandy, 1953, Jour. Paleont., vol. 27, No. 2, p. 179, pl. 22, fig. 6.
- Rotorbinella versiformis* (Bandy) = *Rotalia versiformis* Bandy, 1953, Jour. Paleont., vol. 27, No. 2, p. 179, pl. 22, fig. 5.
- Saracenaria angularis* Natland, 1938, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 4, No. 5, p. 143, pl. 5, figs. 1-2.
- Siphotextularia flinti* (Cushman) = *Textularia flinti* Cushman, 1911, U.S. Nat. Mus., Bull., No. 71, p. 21, fig. 36 a-b.
- Sigmoilina tenuis* (Czjzek) = *Quinqueloculina tenuis* Czjzek, 1848, Haidinger's Naturw. Abh., vol. 2, p. 149, p. 13, figs. 31-34.
- Sphaeroidina bulloides* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 267, pl. 98, fig. 18; Modèles, No. 65.
- Sphaeroidina variabilis* Reuss, 1851, Deutsch. Geol. Ges. Zeitschr., vol. 3, p. 88, pl. 7, figs. 61-64.
- Spiroloculina dentata* Cushman and Todd, 1944, Cushman Lab. Foram. Res., Spec. Pub. 11, p. 71, pl. 9, figs. 33-34.

- Stainforthia complanata* (Egger) = *Virgulina schreibersiana* Czjzek var. *complanata* Egger, 1893, K. Bayer. Akad. Wiss. München., Abh., Math-Physik. Kl., Kl. 2, vol. 18, pt. 2, p. 292, pl. 8, figs. 91-92.
- Stainforthia nodosa* (R. E. and K. C. Stewart) = *Virgulina nodosa* R. E. and K. C. Stewart, 1930, Jour. Paleont., vol. 4, No. 1, p. 64, pl. 8, fig. 4.
- Stilostomella adolphina* (d'Orbigny) = *Dentalina adolphina* d'Orbigny, 1846, *Foraminifères fossiles du bassin tertiaire de Vienna*. Gide et Comp., p. 51, pl. 2, figs. 18-20.
- Stilostomella advena* (Cushman and Laiming) = *Nodogerina advena* Cushman and Laiming, 1931, Jour. Paleont., vol. 5, No. 2, p. 106, pl. 11, fig. 19.
- Stilostomella irregularis* (Kleinpell) = *Nodogenerina irreguaris* Kleinpell, 1938, *Miocene stratigraphy of California*, Am. Assoc. Petrol. Geol., 1, 245, pl. 17, fig. 12.
- Suggrunda eckisi* Natland, 1950, Geol. Soc. America, Mem. 43, pt. 4, p. 23, pl. 9, fig. 12.
- Textularia conica* d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, *Foraminifères*, p. 143, pl. 1, figs. 19-20.
- Textularia vola* Lalicker and McCulloch, 1940, Allan Hancock Pacific Exped., vol. 6, No. 2, p. 142.
- Triloculina inornata longidentata* Bandy, 1953, Jour. Paleont., vol. 27, No. 2, p. 178, pl. 21, fig. 2.
- Triloculina tricarinata* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 299, Modèles, No. 94.
- Triloculina trigonula* (Lamarck) = *Miliolites trigonula* Lamarck, 1804, Paris, Mus. Nat. Hist., Ann., vol. 5, p. 351; 1807, idem, vol. 9, pl. 17, fig. 4.
- Trochammina inflata* (Montagu) = *Nautilus inflatus* Montagu, 1808, Test. Brit., Suppl., p. 81, pl. 18, fig. 3.
- Trochammina pacifica* Cushman, 1925, Cushman Lab. Foram. Res., Contr., vol. 1, pt. 2, p. 39, pl. 6, figs. 3 a-c.
- Trochammina vesicularis* Göes, 1894, Königl. Svensk. Vet. Akad. Handl., vol. 25, No. 9, p. 31, pl. 6, figs. 235-237.
- Uvigerina hispida* Schwager, 1866, Novara Exped., Geol. Theil., Ed. 2, Abth. 2, p. 249, pl. 7, fig. 95.
- Uvigerina hispidocostata* Cushman and Todd, 1945, Cushman Lab. Foram. Res., Spec. Pub., No. 15, p. 51, pl. 7, figs. 27, 31.
- Uvigerina bootsi bootsi* Rankin, 1934, in Cushman and Kleinpell, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 22, pl. 3, figs. 8-9.
- Uvigerina bootsi magnifica* (Bramlette) = *Hopkinsina magnifica* Bramlette, 1950, U.S. Geol. Sur., Prof. Paper 222, p. 59, pl. 22, figs. 1-3.
- Uvigerina bootsi modeloensis* (Cushman and Kleinpell) = *Uvigerina modeloensis* Cushman and Kleinpell, 1934, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 12, pl. 2, fig. 8.
- Uvigerina juncea* Cushman and Todd, 1941, Cushman Lab. Foram. Res., Contr., vol. 17, pt. 3, p. 78, pl. 20, figs. 4-11.
- Uvigerina kernensis* Barbat and von Estorff, 1933, Jour. Paleont., vol. 7, No. 2, pl. 23, fig. 13.
- Uvigerina peregrina* Cushman, 1923, U.S. Nat. Mus., Bull. 104, pt. 4, p. 166, pl. 42, figs. 7-10; specimens commonly ascribed to *U. subperegrina* by authors were herein included with *U. peregrina*.
- Uvigerina proboscidea* Schwager, 1866, Novara-Exped., Geol. Teil, vol. 2, pt. 2, p. 250, pl. 7, fig. 96.
- Uvigerina segundoensis* Cushman and Galliher, 1934, Cushman Lab. Foram. Res., Contr., vol. 10, pt. 1, p. 26, pl. 4, fig. 11.
- Uvigerina senticosa* Cushman, 1927, Univ. California, Scripps Inst. Oceanogr., Bull., Tech. Ser., vol. 1, p. 159, pl. 3, fig. 14.

- Valvulineria alicia* Pierce, 1956, Jour. Paleont., vol. 30, No. 6, p. 1,306, pl. 141, fig. 3.
Valvulineria araucana araucana (d'Orbigny) = *Rosalina araucana* d'Orbigny, 1839, Voy. Amér. Mèrid., Foraminifères, vol. 5, pt. 5, p. 44, pl. 6, figs. 16-18.
Valvulineria araucana malagaensis Kleinpell, 1938, Miocene stratigraphy of California, Amer. Assoc. Petrol. Geol., p. 308, pl. 22, figs. 10-12.
Valvulineria inequalis d'Orbigny, 1839, Voy. Amér. Mèrid., Foraminifères, vol. 5, pt. 5, p. 48, pl. 7, figs. 10-12.

RADIOLARIA

- Prunopyle titan* Campbell and Clark, 1944, Geol. Soc. America, Spec. Paper No. 51, p. 20, pl. 3, figs. 1-3.

APPENDIX

TABLE 6 - RELATIVE ABUNDANCE OF PLANKTONIC FORAMINIFERA IN RECENT SEDIMENTS, MARGINAL EASTERN PACIFIC

SAMPLE NO.	AHF 3007	AHF 3010	AHF 3011	AHF 4881	AHF 5819	AHF 6373	AHF 7241	AHF 9775	AHF 0621	OS-1 ²	AC-2 ³	LU-3 ³	H-13 ³
PLANKTONIC SPECIES													
GLOBIGERINA BULLOIDES BULLOIDES	8	12	27	32	7	16	17	9	23	28	12		8
GLOBIGERINA BULLOIDES QUADRILATERA	3	1	2		2		1	2	8				
GLOBIGERINA EGGERI EGGERI	20	11	8	5	5		11	2	2		30	58	62
GLOBIGERINA EGGERI--VARIANTS		4	1	6			16						
GLOBIGERINA PACHYDERMA	54	45	25	6	63	X	27	34	42	32			
PERCENT SINISTRAL SPECIMENS	2				1		37		2	91			
GLOBIGERINA QUINQUELOBA	10	16	25	49	15	79	12	22	15	12			
GLOBIGERINELLA SIPHONIFERA	X	X	X				X		X				
GLOBIGERINITA GLUTINATA	2	2	1	X	1		3		2	11			
GLOBIGERINITA HUMILIS		X					X		X				
GLOBIGERINITA UVULA	X	2	3	2	6		4	26	X	14			
GLOBIGERINOIDES RUBER	X	2	4	6	1	5	1	2	2		14	18	20
GLOBIGERINOIDES TRILOBUS SACCULIFER											9	5	3
GLOBIGERINOIDES TRILOBUS TRILOBUS							X						
GLOBOROTALIA CRASSAFORMIS ⁴	X												
GLOBOROTALIA HIRSUTA	X	X					X	1	1				
GLOBOROTALIA INFLATA		X					X		X		9		
GLOBOROTALIA MENARDI MENARDI											5	12	5
GLOBOROTALIA MENARDI TUMIDA							X				22	5	
GLOBOROTALIA SCITULA	X								X	1			
GLOBOROTALIA TRUNCATULINOIDES	X						X	X	X				
GLOBOROTALOIDES HEXAGONUS	1	X					1		X				
"ORBULINA" CHAMBERS	3	3	2		X		3	1	3	X			X
PULLENIATINA OBLIQUICULATA												2	1
"SPHAERODINELLA DEHISCENS"											(X)	(X)	(X)
SPECIMENS COUNTED	393	437	201	143	360	56	412	419	316	272			

¹ALLAN HANCOCK FOUNDATION SAMPLE⁴POSSIBLE FOSSILABUNDANCE GIVEN AS PERCENT OF
TOTAL PLANKTONIC POPULATION²OREGON STATE UNIVERSITY SAMPLE³FROM BANDY AND ARNAL (1956)

Table 6.—Relative abundance of planktonic Foraminifera in Recent sediments of the marginal eastern North Pacific.

TABLE 7—RELATIVE ABUNDANCE OF
FORAMINIFERA, MALAGA MUDSTONE,
U.S.G.S. LOC. 24, SAN PEDRO

<u>PLANKTONIC SPECIES</u>	
GLOBIGERINA BULLOIDES BULLOIDES	52
GLOBIGERINA BULLOIDES QUADRILATERA	22
GLOBIGERINA PACHYDERMA	11
PERCENT SINISTRAL SPECIMENS	73
GLOBIGERINA QUINQUELOBA	1
GLOBIGERINITA UVULA	1
GLOBOROTALIA HIRSUTA	x
GLOBOROTALIA SCITULA	2
"ORBULINA" CHAMBERS	10
<u>BENTHIC SPECIES</u>	
ASTRONOMION SPP.	x
BAGGINA CALIFORNICA	1
BOLIVINA BRAMLETTEI	x
BOLIVINA DECURTATA	x
BOLIVINA SEMINUDA FORAMINATA	1
BOLIVINA SEMINUDA HUMILIS	2
BOLIVINA SNUATA	x
BOLIVINA SUBADVENA	x
BOLIVINA TONGI FILICOSTATA	x
BOLIVINA VAUGHANI	x
BULIMINA PAGODA PAGODA	x
BULIMINA PAGODA HEBESPINATA	2
BULIMINA SUBACUMINATA	x
BULIMINELLA BREVIOR	x
BULIMINELLA CURTA	6
BULIMINELLA SUBFUSIFORMIS	3
CASSIDELLA CALIFORNIENSIS	5
CASSIDULINA CUSHMANI	1
CASSIDULINA DELICATA	8
CASSIDULINA MODELOENSIS	1
CHILOSTOMELLA OVOIDEA	x
EPONIDES HEALDI	x
GLOBOBULIMINA MARGINOSPINATA	x
GLOBOBULIMINA OVULA OVULA	6
GLOBOBULIMINA OVULA PEDROANA	1
GLOBOBULIMINA PACIFICA	2
GYROIDINA KEENANI	2
GYROIDINA MULTICAMERATA	10
GYROIDINA ROTUNDIMARGO	x
LAGENA ALOCKI	x
NODOSARIA LONGISCATA	x
ROBULUS SP.	x
STILOSTOMELLA ADVENA	x
UVIGERINA HISPIDOCOSTATA	x
UVIGERINA HOOTSI HOOTSI	39
UVIGERINA HOOTSI MAGNIFICA	2
VALVULINERIA ARAUCANA ARAUCANA	2
VALVULINERIA ARAUCANA MALAGAENSIS	2
NUMBER PLANKTONIC SPECIMENS COUNTED	261
NUMBER BENTHONIC SPECIMENS COUNTED	229
PERCENT PLANKTONIC SPECIES	11
PERCENT BENTHONIC SPECIES	89
<u>RADIOLARIANS</u>	
PERCENT SPUMELLINA	85
PERCENT NASSELLINA	15

SPECIES ABUNDANCE GIVEN AS PERCENT OF TOTAL
BENTHIC OR PLANKTONIC FAUNA

x = LESS THAN 1 PERCENT

Table 7.—Relative abundances of Foraminifera in the Malaga Mudstone, U.S.G.S. locality 24 (see Woodring, Bramlette, and Kew, 1964), Palos Verdes Hills, Los Angeles County, California. Sample collected by O. L. Bandy prior to destruction of sample locality.

TABLE 9 — RELATIVE ABUNDANCE OF PLANKTONIC FORAMINIFERA, REPETTO FORMATION, BUNKER HILL SECTION

SAMPLE NO.	4	6	8	10	11	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
PLANKTONIC SPECIES																				
GLOBIGERINA BULLOIDES BULLOIDES	50	1	2	9	22	15	16	6	1	14	9	4	1	2				3	5	3
GLOBIGERINA BULLOIDES QUADRILATERA						3	5	X	X	X	1	X	X	X					2	
GLOBIGERINA EGGERI EGGERI	9		1	7	9	3	3	3	3	2	2	4	1	1	1	10				
GLOBIGERINA EGGERI--VARIANTS	34		17	18	26	36	22	34	19	31	48	89	86	91	50	84	80	73	75	
GLOBIGERINA PACHYDERMA	30	45	X	47	48	39	40	48	56	63	54	41	5	7	4	40	9	9	19	12
PERCENT SINISTRAL SPECIMENS			2	2	20	10	5	2	2	29	5	2							4	19
GLOBIGERINA QUINQUELOBA		X	X	X	X	4		6	X	X	X		X	1	X					
GLOBIGERINITA GLUTINATA	20		2	5		X		9	3	1	X	X	X	X	X					
GLOBIGERINITA UVULA			X			X							X							
GLOBIGERINOIDES RUBER					1	3			X		X				X					
GLOBIGERINOIDES TRILOBUS				X																
GLOBOROTALIA CRASSAFORMIS				X	X		4	X		X	X			X						
GLOBOROTALIA HIRUTA	X							X		X	X		X	X				X		X
GLOBOROTALIA INFLATA	1	80	6	X				X		X	X		X	X						
GLOBOROTALIA MENARDI MENARDI																				
GLOBOROTALIA MENARDI TUMIDA			2	X										1	X	1		X	X	X
GLOBOROTALOIDES HEXAGONUS			X					2												
"ORBULINA" CHAMBERS	10	11	13	3	X	2	X	2	X									3	1	X
"SPHAERODINELLA DEHISCENS"										1	X			X	X					
SPECIMENS COUNTED	10	320	161	240	165	74	58	192	181	147	329	236	482	441	765	30	543	505	295	8

Table 9.—Relative abundances of planktonic Foraminifera in the Repetto Formation, Bunker Hill section, Los Angeles County, California. Abundance given as percentage of total planktonic population. Samples were originally collected by Martin (1952).

TABLE 13.—RELATIVE ABUNDANCE OF PLANKTONIC FORAMINIFERA,
PICO FORMATION, BALCOM CANYON SECTION

PLANKTONIC SPECIES	SAMPLE NO.																	
	1	2	3	4	5	6	7	8	9	10	11	12 ¹	13	14	15 ¹	16	17	18
GLOBIGERINA BULLOIDES BULLOIDES	30	11	14	17	6	6	13	16	24	9	22	X	13	7		16	5	10
GLOBIGERINA BULLOIDES QUADRILATERA	6		8	4	X	2	4	2	6	1	6		1	X		3	X	
GLOBIGERINA EGGERI EGGERI	X	2		1	1	X	X	2	X	X	X					1		X
GLOBIGERINA EGGERI--VARIANTS	2		2	1	X	1	X	1	X	1	X					X	X	
GLOBIGERINA PACHYTERMA	44	61	64	61	70	80	74	63	53	41	33		6	7		29	12	10
PERCENT SINISTRAL SPECIMENS	11	26	35	83	93	90	77	21	63	76	37		38	20		53	11	19
GLOBIGERINA QUINQUELOBA	17	11	8	9	11	5	2	9	11	28	25	X	64	66		33	66	46
GLOBIGERINITA GLUTINATA	X	4	1	1	2	1	2	1	X	3	1		4	3		1	9	4
GLOBIGERINITA UVULA	1	4	3	6	8	4	X	3	2	12	7		12	16		15	12	29
GLOBIGERINOIDES RUBER	X				1	X			X									
GLOBOROTALIA CRASSA FORMIS				X	X	X					X						X	
GLOBOROTALIA HIRSUTA				X						X			X				1	X
GLOBOROTALIA INFLATA				X	X	X	2	2	1	4	4		X					
GLOBOROTALIA SCITULA				X	X	X												
GLOBOROTALIA TRUNCATULINOIDES					X				X									
GLOBIGERINA - QUANTITIES	X			X	X	X	2			X	1							
SPECIMENS COUNTED	382	56	132	380	360	395	312	170	377	356	395	6	264	138		199	331	209

¹TURBIDITE SAID

Table 13.—Relative abundances of planktonic Foraminifera, Pico Formation, Balcom Canyon section, Ventura County, California. Abundance given as percentage of total planktonic population.

Table 14
Location of Allan Hancock Foundation samples

Station Number	Latitude North	Longitude West	Depth in Fathoms
AHF-3007	33° 38' 31"	118° 23' 27"	458
AHF-3010	33° 40' 28"	118° 20' 39"	287
AHF-3011	33° 41' 37"	118° 19' 49"	37
AHF-4881	33° 37' 53"	118° 01' 52"	14
AHF-5819	33° 34' 40"	118° 03' 13"	98
AHF-6373	33° 39' 25"	118° 01' 00"	5
AHF-7241	27° 41' 40"	115° 33' 35"	1500
AHF-9775	33° 30' 30"	117° 55' 20"	82
AHF-10621	32° 31' 50"	119° 33' 20"	690

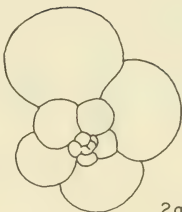
PLATES

EXPLANATION OF PLATE 33

Figure	Page
1. Globigerina bulloides bulloides d'Orbigny	356
Upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 1; a, spiral view; b, umbilical view; b, umbilical view; X 95.	
2. Globigerina bulloides bulloides d'Orbigny	356
Lower Pliocene, Repetto Formation (Venturian Stage benthic fauna), Woodland Hills section, sample 74; a, spiral view; b, umbilical view; X 95.	
3. Globigerina bulloides bulloides d'Orbigny ...	356
Upper Miocene, Modelo Formation (Delmontian Stage benthic fauna), Woodland Hills section, sample 30; a, spiral view; b, umbilical view; X 100.	
4. Globigerina bulloides quadrilatera (Galloway and Wissler) ...	356
Upper Miocene, Monterey Shale (upper Mohnian Stage benthic fauna), Newport Mesa section, sample 25; a, umbilical view; b, edge view; c, spiral view.	
5. Globigerina druryi decoraperta Takayanagi and Saito .	292
Upper Miocene, Modelo Formation (upper Mohnian Stage benthic fauna), Woodland Hills section, sample 1; a, spiral view; b, edge view; c, umbilical view; X 100.	
6. Globigerina pachyderma (Ehrenberg)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 12; a, spiral view; b, edge view; c, umbilical view; X 60.	
7. Globigerina pachyderma (Ehrenberg)	356
Upper Pliocene, Pico Formation (Hallian Stage benthic fauna), New- port Mesa section, sample 84; a, spiral view; b, edge view; c, umbilical view; X 100.	



1a



2a



3a



1b



2b



3b



4a



4b



4c



5a



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7a



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7c



6c



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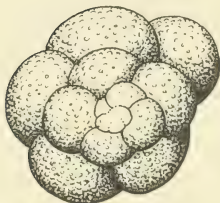
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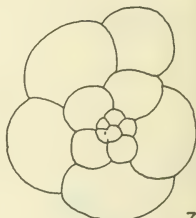
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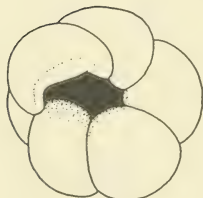
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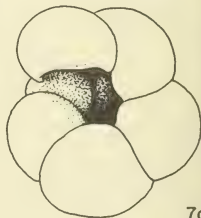
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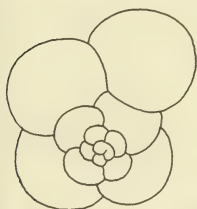
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EXPLANATION OF PLATE 34

Figure	Page
1. Globigerina pachyderma (Ehrenberg)	356
Upper Pliocene, Pico Formation (Wheelerian Stage benthic fauna), Balcom Canyon section, sample 1: a, spiral view; b, edge view; c, umbilical view; X 85.	
2. Globigerina pachyderma (Ehrenberg)	356
Upper Miocene, Modelo Formation (Delmontian Stage benthic fauna), Woodland Hills section, sample 35; a, umbilical view; b, spiral view; X 100.	
3. Globigerina pachyderma (Ehrenberg)	356
Lower Pliocene, Repetto Formation (Wheelerian Stage benthic fauna), Woodland Hills section, sample 80; a, spiral view; b, umbilical view; X 100.	
4. Globigerina pachyderma (Ehrenberg)	356
Upper Miocene, Modelo Formation (upper Mohnian Stage benthic fauna), Woodland Hills section, sample 6; a, spiral view; b, um- bilical view; X 100.	
5. Globigerina eggeri eggeri Rhumbler	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 13; a, spiral view; b, edge view; c, umbilical view; X 125.	
6. Globigerina eggeri eggeri Rhumbler	356
Lower Pliocene, Capistrano Formation (Repettian Stage benthic fauna), Newport Mesa section, sample 51; a, spiral view; b, edge view; c, umbilical view; X 85.	
7. Globigerina eggeri —variant	356
(Depressed spiral side), Lower Pliocene, Capistrano Formation (Re- pettian Stage benthic fauna), Newport Mesa section, sample 50; a, spiral view; b, edge view; c, umbilical view; X 85.	

EXPLANATION OF PLATE 35

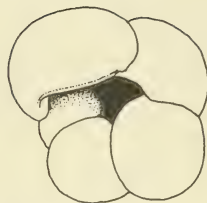
Figure	Page
1. Globigerina eggeri —variant	356
(Low spiral side, quadrate outline), upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 1; a, spiral view; b, edge view; c, umbilical view; X 85.	
2. Globigerina eggeri —variant	356
(Flat spiral side, four appressed chambers in final whorl), lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 35; a, spiral view; b, edge view; c, umbilical view; X 90.	
3. Globigerina eggeri —variant	356
(Flat spiral side, four appressed chambers in final whorl), lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 33; a, spiral view; b, edge view; c, umbilical view; X 75.	
4. Globigerina eggeri —variant	356
(Flat spiral side, four appressed chambers in final whorl) lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 38; a, spiral view; b, edge view; c, umbilical view; X 85.	
5. Globigerina quinqueloba Natland	356
Lower Pliocene, Pico Formation (Hallian Stage benthic fauna), Balcom Canyon section, sample 17; a, spiral view; b, edge view; c, umbilical view; X 100.	
6. Globigerina quinqueloba Natland	356
Lower Pliocene, Repetto Formation (Wheelerian Stage benthic fauna), Woodland Hills section, sample 81; a, spiral view; b, umbilical view; X 100.	



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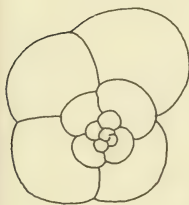
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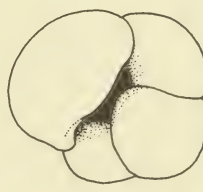
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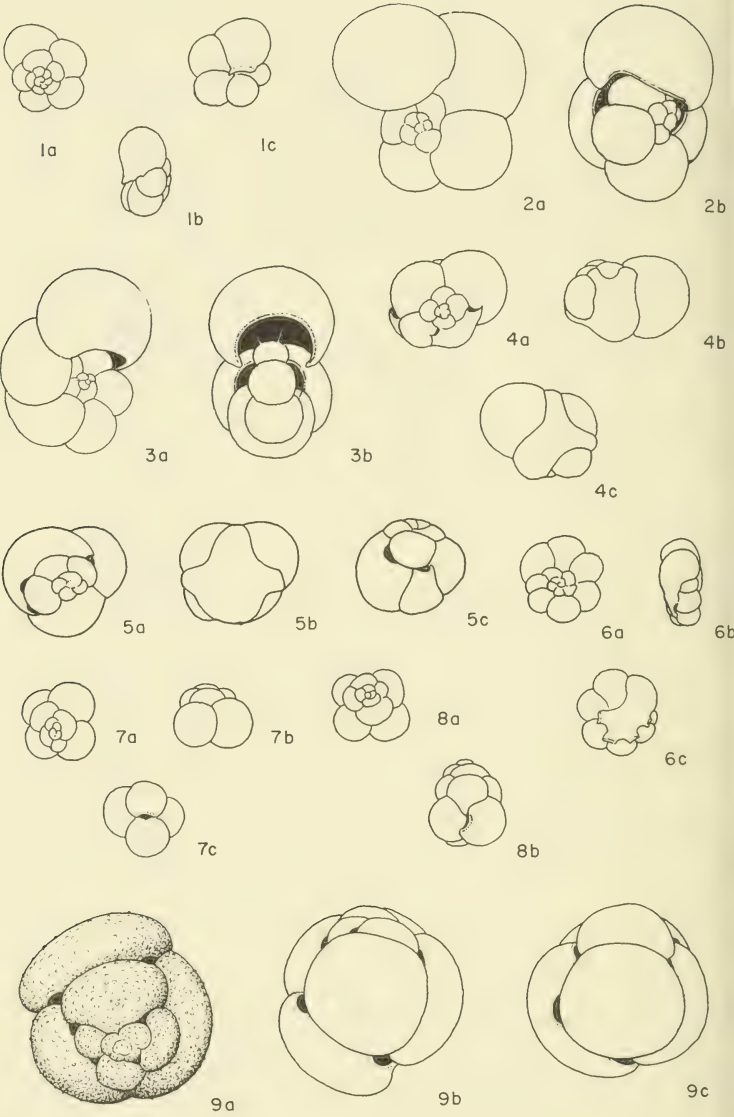
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EXPLANATION OF PLATE 36

Figure	Page
1. Globigerina quinqueloba Natland	356
Upper Miocene, Modelo Formation (Delmontian Stage benthic fauna), Woodland Hills section, sample 35; a, spiral view; b, edge view; c, umbilical view; X 100.	
2. Globigerinella siphonifera (d'Orbigny)	356
Upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 1; a, spiral view; b, edge view; X 70.	
3. Globigerinella siphonifera (d'Orbigny)	356
Upper Pliocene, Pico Formation (Hallian Stage benthic fauna), Newport Mesa section, sample 85; a, spiral view; b, edge view; X 70.	
4. Globigerinita glutinata (Egger)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 18; a, spiral view; b, edge view; c, umbilical view; X 100.	
5. Globigerinita glutinata (Egger)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 41; a, spiral view; b, umbilical view; c, edge view; X 100.	
6. Globigerinita humilus Parker	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 20; a, spiral view; b, edge view; c, umbilical view; X 100.	
7. Globigerinita uvula (Ehrenberg)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 7; a, spiral view; b, edge view; c, umbilical view; X 150.	
8. Globigerinita uvula (Ehrenberg)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 41; a, spiral view; b, edge view; X 150.	
9. Globigerinoides conglobatus (Brady)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 36; a, spiral view; b, edge view; c, edge view; X 70.	

EXPLANATION OF PLATE 37

Figure	Page
1. Globigerinoides ruber (d'Orbigny)	356
Upper Pliocene, Pico Formation (Hallian Stage benthic fauna), Newport Mesa section, sample 83; a, spiral view; b, edge view; X 60.	
2. Globigerinoides ruber (d'Orbigny)	356
Upper Pliocene, Pico Formation (Wheelerian Stage benthic fauna), Balcom Canyon section, sample 5; a, spiral view; b, edge view; X 90. This form is commonly referred to <i>Globigerinoides cyclostomus</i> Galloway and Wissler.	
3. Globigerinoides ruber (d'Orbigny)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 36; a, spiral view; b, edge view; X 90.	
4. Globigerinoides trilobus immaturus (LeRoy)	356
Upper Miocene, Modelo Formation (upper Mohnian Stage benthic fauna), Woodland Hills section, sample 2; a, spiral view; b, umbilical view; X 100.	
5. Globigerinoides trilobus sacculifer (Brady)	356
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 20; a, spiral view; b, umbilical view; X 50.	
6. Globigerinoides trilobus trilobus (Reuss)	356
Early Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 31; a, spiral view; b, edge view; c, side view; X 60.	



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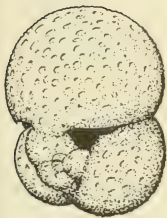
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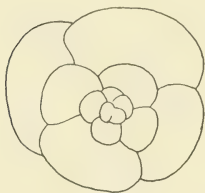
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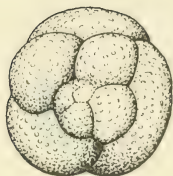
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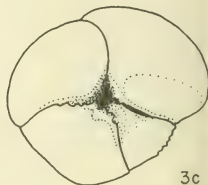
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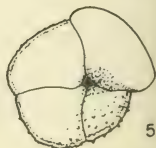
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EXPLANATION OF PLATE 38

Figure	Page
1. Globoquadrina conglomerata (Schwager)	357
Upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 1; a, spiral view; b, edge view; c, um- bilical view; X 80.	
2. Globoquadrina conglomerata (Schwager)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 35; a, spiral view; b, edge view; c, umbilical view; X 80.	
3. Globorotalia crassaformis (Galloway and Wissler)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 12; a, dorsal view; b, edge view; c, ventral view; X 90.	
4. Globorotalia crassaformis (Galloway and Wissler)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 33; a, dorsal view; b, edge view; c, ventral view; X 90.	
5. Globorotalia crassaformis (Galloway and Wissler)	357
Upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 1; a, dorsal view; b, edge view; c, ventral view; X 90.	

EXPLANATION OF PLATE 39

Figure	Page
1. Globorotalia hirsuta (d'Orbigny)	357
Upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 1; a, dorsal view; b, edge view; c, ventral view; X 100.	
2. Globorotalia hirsuta (d'Orbigny)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 36; a, dorsal view; b, edge view; c, ventral view; X 90.	
3. Globorotalia hirsuta (d'Orbigny)	357
Upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 1; a, dorsal view; b, edge view; c, ventral view; X 90.	
4. Globorotalia inflata (d'Orbigny)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 34; a, dorsal view; b, edge view; c, ventral view; X 90.	
5. Globorotalia inflata (d'Orbigny)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic Stage fauna), Repetto Hills section, sample 36; a, dorsal view; b, edge view; c, ventral view; X 90.	



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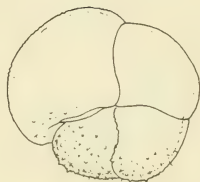
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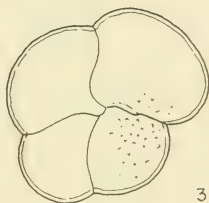
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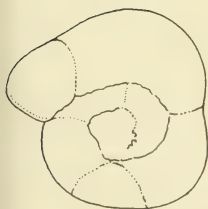
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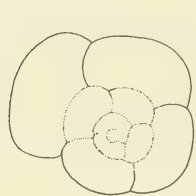
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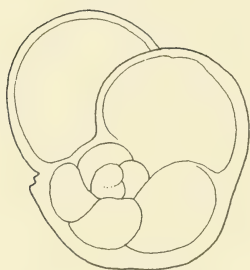
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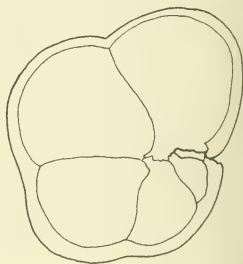
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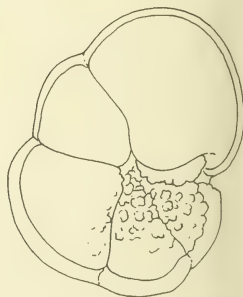
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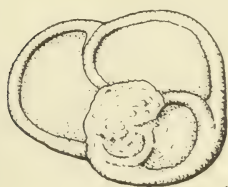
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EXPLANATION OF PLATE 40

Figure	Page
1. Globorotalia inflata (d'Orbigny)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 40; a, dorsal view; b, edge view; c, ventral view; X 90.	
2. Globorotalia mayeri Cushman and Ellisor	357
Upper Miocene, Monterey Shale (lower Mohnian Stage benthic fauna), Newport Mesa section, sample 81 a, dorsal view; b, edge view; c, ventral view; X 110.	
3. Globorotalia menardi menardi (d'Orbigny)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Bunker Hill section, sample 19; a, dorsal view; b, edge view; c, ventral view; X 100.	
4. Globorotalia menardi tumida (Brady)	357
Lower Pliocene, Capistrano Formation (Repettian Stage benthic fauna), Newport Mesa section, sample 51; a, dorsal view; b, edge view; c, ventral view; X 80.	

EXPLANATION OF PLATE 41

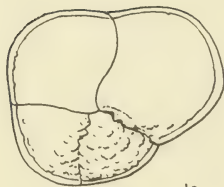
Figure	Page
1. Globorotalia menardi tumida (Brady)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 33; a, dorsal view; b, edge view; c, ventral view; X 100.	
2. Globorotalia menardi tumida (Brady)	357
Upper Pliocene, San Diego Formation (Hallian Stage benthic fauna), Pacific Beach section, sample 2; a, dorsal view; b, edge view; c, ventral view; X 100.	
3. Globorotalia menardi tumida (Brady)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Malaga Cove section, sample 40; a, dorsal view; b, edge view; c, ventral view; X 125.	
4. Globorotalia menardi tumida (Brady)	292, 357
Smooth, "non-crystalline" wall. Upper Miocene, Monterey Shale (upper Mohnian Stage benthic fauna), Tecolote Tunnel, Inlet Portal section, sample 2075 (Bandy and Kolpack, 1963); a, dorsal view; b, edge view; c, ventral view; X 90.	
5. Globorotalia scitula (Brady)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 17; a, dorsal view; b, edge view; c, ventral view; X 90.	



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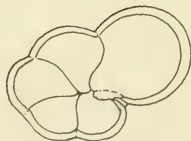
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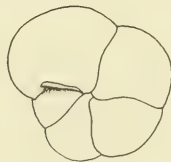
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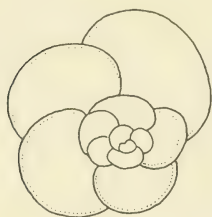
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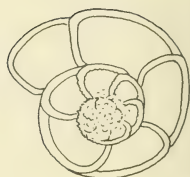
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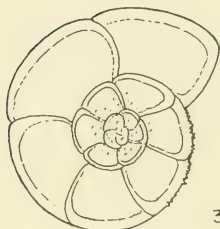
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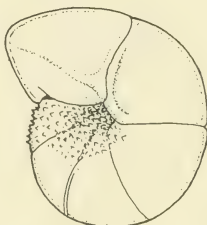
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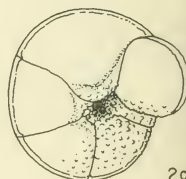
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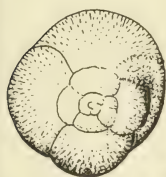
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EXPLANATION OF PLATE 42

Figure	Page
1. Globorotalia scitula (Brady)	357
Upper Miocene, Malaga Mudstone Member, Monterey Shale (Delmontian Stage benthic fauna), U.S.G.S. locality 24 (Woodring, Bramlette and Kew, 1946) San Pedro, California; a, dorsal view; b, edge view; X 130.	
2. Globorotalia truncatulinoides (d'Orbigny)	357
Upper Pliocene, Pico Formation (Hallian Stage benthic fauna), Newport Mesa section, sample 86; a, dorsal view; b, edge view; c, ventral view; X 90.	
3. Globorotalia truncatulinoides (d'Orbigny)	357
Upper Pliocene, Pico Formation (Wheelerian Stage benthic fauna), Balcom Canyon section, sample 5; a, dorsal view; b, edge view; c, ventral view; X 100.	
4. Globorotaloides hexagonus (Natland)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 14; a, spiral view; b, edge view; c, side view; X 90.	
5. Globorotaloides hexagonus (Natland)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 11; a, spiral view; b, edge view; c, side view; X 90.	

EXPLANATION OF PLATE 43

Figure	Page
1. Pulleniatina obliquiloculata (Parker and Jones)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 21; a, spiral view; b, edge view; X 95.	
2. "Sphaeroidinella dehiscens" (Parker and Jones)	357
Lower Pliocene, Repetto Formtion (Repettian Stage benthic fauna), Repetto Hills section, sample 18; a, side view; b, edge view; X 100.	
3. "Sphaeroidinella dehiscens" (Parker and Jones)	357
Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Bunker Hill section, sample 18; a, side view; b, edge view; X 90.	
4. "Sphaeroidinella dehiscens" (Parker and Jones)	357
Specimen contains <i>Globigerinoides trilobus sacculifer</i> beneath cortex; note outline. Lower Pliocene, Repetto Formation (Repettian Stage benthic fauna), Repetto Hills section, sample 40; side view; X 80.	
5. Sphaeroidinellopsis subdehiscens (Blow)	357
Upper Miocene, Modelo Formation (upper Mohnian Stage benthic fauna), Woodland Hills section, sample 6; a, spiral view; b, apertural view; X 90.	
6. Sphaeroidinellopsis sudbehiscens (Blow)	357
Upper Miocene, Modelo Formation (upper Mohnian Stage benthic fauna), Woodland Hills section, sample 6; a, spiral view; b, edge view; c, apertural view; d, edge view; X 90.	
7. Sphaeroidinellopsis seminulina (Schwager)	357
Upper Miocene, Modelo Formation (upper Mohnian Stage benthic fauna), Mission Hills section, sample 9; X 90.	
8. Prunopyle titan Campbell and Clark	366
(Radiolarian), upper Miocene, Valmonte Diatomite Member, Monterey Shale (upper Mohnian Stage), Malaga Cove section, sample 6; a, side view; b, apertural view; X 90.	



1a



1b



3a



2a



2b



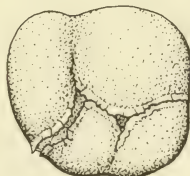
3b



5a



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4



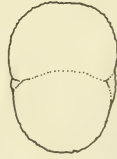
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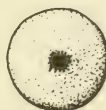
7a



7b



8a



8b

INDEX

Note: Light face figures refer to the page number. Bold face figures refer to the plate number.

A

acuminata, Bolivia	246
acutula, Bolivia	245
adolphina, Stilostomella	247
advena, Stilostomella	247
advena, Bolivia	246
affinis, Bulimina	246
akneriana,	
Quinqueloculina	245
Alaska	238, 239
Aleutian area	316
Allan Hancock	
Foundation	218, 236
altiformis, Gyroidina	246
altispira, Globoquadrina	321
American Association of	
Petroleum Geologists	218
Ammonia beccari tepida	245
Angulogerina angulosa	246, 288, 289
Angulogerina baggi	245
angulosa, Angulogerina	246, 288, 289
Antarctica,	291
onset of glaciation in	291
evidence of Miocene	
glaciation	316
araucana, Valvulineria	247, 254, 270
Arctic	291
arenaria, Gaudryina	246
argentina, Bolivia	246
Armuelles Formation,	
Panama	330
Atlantic Ocean	278, 282, 306
auricula, Cancris	245
Australia	282

B

baggi, Trochammina	245
Baja California, Mexico	238, 274, 303, 307, 319, 320
Balcom Canyon section,	
California	221, 229, 232, 248, 287, 289, 303, 305, 317, 319, 336, 338
dominant benthic	
species	288
paleobathymetry of	288, 289
planktonic biofacies	288
potassium-argon date in	288

bank tops	225, 258
barbarana, Cassidulina	246
barleanus, Melonis	246
base of the Pliocene	277
basispinata, Nonionella	235, 245, 288, 289
benedictensis, Bolivia	247, 270
Bolivia acuminata	246
acutula	245
argentea	246
benedictensis	247, 270
brevior	247
goudkoffi	273
granti	273
hootsi	273
hughesi	247, 254, 273
interjuncta	235, 246, 288
obliqua	247, 266, 273
obliqua zone	266
pacifica	246
parva	240, 273
pseudoplicata	246
pseudospissa	247, 254, 270
rankini	238, 247, 273, 276, 337
seminuda	238, 247, 254, 270, 273
sinuata	246, 254
spissa	246, 264
subadvena sulphurensis	246
tongi filicostata	245
Torqueata	246
vaughani	245
boreal planktonic faunas	278, 282, 284, 293
bradyana, Epistominella	235
brevior, Bolivia	247
Buccella frigida	245
tenerrima	245
Bulimina affinis	246
marginata denudata	246, 288, 289
pagoda hebespinata	246, 256
rostrata	238, 247, 263
striata mexicana	235
subacuminata	246, 256
subcalva	246
uvigerinaformis	240
Buliminella curta	246, 273
ecuadorana	246
elegantissima	239, 245, 263
subfusiformis	246, 264

INDEX

- bulloides, *Globigerina* ..33 280, 281, 282,
283, 284, 287,
288, 290, 292,
294, 296, 298,
300, 304, 307,
309, 310, 313,
321, 327, 334,
338, 339
- bulloides, *Pullenia* 235, 247, 263,
264
- Bunker Hill section,
California, 221, 225, 227,
234, 236, 264,
265, 297, 302,
317, 335
- planktonic Foraminifera
Burica Formation, Panama 301
330
- ## C
- californica, *Cassidulina* 246
- californiensis, *Virgulina* .. 240
- Cambell Grab 236
- Canal Zone 328
- Cancris auricula 245
- Capistrano area,
California 307
- Capistrano Embayment,
California 241
- Capistrano-Dana Point
section, California 240
- Carmen Basin, Gulf of
California 255
- Cassidulina barbarana* 246
- californica 246
- cushmani 235, 246
- delicata 235, 246
- limbata 246
- modeloensis 246
- minuta 246
- subglobosa subglobosa .. 246
- subglobosa quadrata 246
- tortuosa 235, 246
- translucens 235, 246, 264
- Catalina Island, California 250
- Catalina Schist, California 258
- Cedro Deep, Mexico 324
- Central America 238, 239, 274
- Charco Azul Formation,
Panama 234, 328, 330
- Chilostominella czizeki* 246
- ovoidea 246
- Cibicides lobatus* 245
- mckannai 246, 264
- coiling ratios,
Globigerina eggeri 293, 310
- Globigerina pachyderma* 284, 285, 288,
290, 291, 296,
396, 301, 310,
327, 330
- conglobatus,
Globigerinoides36 279, 280, 290
295, 296, 298,
300, 307, 310
321, 334, 339
- conglomerata,
Globoquadrina38 280, 284, 296,
298, 300, 301,
307, 310, 321,
334, 339
- Continental Borderland,
California 222
- continental slope, 324
- rate of sedimentation on
correlation of epicontinental
and deep-sea sediments 320, 323
- Costa Rica 328
- costata, *Quinqueloculina* .. 245
- crassaformis,
Globorotalia38 284, 285, 288,
290, 295, 296,
300, 304, 310,
321, 326, 327,
334, 338
- crisum, *Elphidium* 235, 245
- Cretaceous 266, 316
- curta, *Buliminella* 246, 273
- cushmani, *Cassidulina* 235, 246
- czizeki, *Chilostomella* 246
- ## D
- Dana Point, California 297
- decoraperta, *Globigerina*
druryi 33 292, 293, 310,
321, 322, 334
- deep-sea sands 260
- definition of geologic units 220
- "dehiscens,
Sphaeroidinella" 43 277, 280, 281,
284, 285, 290, 296,
297, 299, 300, 301,
306, 310, 312, 314,
317, 321, 322, 329,
332, 334, 340
- depth classification 235
- delicata, *Cassidulina* 235, 246

INDEX

Delmontian Stage	229, 238, 239,
	240, 241, 250, 266,
	267, 273, 285, 290,
	294, 295, 296, 310,
	319, 327, 333
diatoms	255
diatomite,	238, 245, 253,
	259, 292
preservation of laminae	259
diatomaceous shale	268, 318
Dietz-La Fond Sampler ..	236
differential rates of sedimentation	318
Discorbinella	
valmonteensis	246, 270
displaced species	245, 247, 248,
	254, 256, 257, 258,
	259, 263, 264, 265,
	273, 288

E

Early Pliocene, planktonic	
biofacies,	325, 328
surface temperatures	313
eckisi, Suggrunda	245, 247, 270
ecuadorana, Buliminella ..	246
effective sill depth	247, 254, 256
elegantissima,	
Buliminella	239, 245, 263
eggeri,	
Globigerina	34, 35 280, 281, 284,
	287, 288, 293, 294,
	296, 297, 298, 300,
	302, 304, 310, 313,
	321, 329, 334, 338
Elphidium crispum,	235, 245
incertum	245
poeyanum translucens..	245
Eocene	244
Epistiminella bradyana	235
pacifica	235
pacifica-smithi	246, 288
subperuviana	246
Europe	333

F

falconensis, Globigerina ..	321
Farallon Basin,	
Gulf of California	255
filicostata, Bolivina tongi..	245
Florida	320

foramininata, Bolivina	
seminuda	247
foshi foshi, Globorotalia ..	284, 322
Foxen Mudstone,	
California	307
frigida, Buccella	245

G

garveyensis, Rotorbinella..	238
Gaudryina arenaria	246
gemma, Gyroidina	247
geologic time scale	220
Geochron Laboratories, Incorporated	220
glaucinite,	225, 250, 257, 258, 259, 302, 330
abundance of	258
glaucophane schist	258, 259
Globigerina bulloides,	33 280, 281, 282, 283, 284, 287, 288, 290, 292, 294, 296, 298, 300, 304, 307, 309, 310, 313, 321, 327, 334, 337, 339
bulloides quadriatera	33
concinna	282, 283, 284 291, 309, 310, 313, 337
eggeri	34, 35 280, 281, 284, 287, 288, 290, 293, 294, 296, 297, 298, 300, 302, 304, 310, 313, 321, 329, 334, 339
falconensis	321
minutissima	321
nepenthes	312
nepenthes zone	314
pachyderma	33, 34 278, 280, 281, 282, 284, 285, 286, 287, 288, 289, 291, 292, 294, 296, 298, 302, 304, 307, 309, 313, 321, 322, 326, 328, 329, 334, 338, 339
quinculoba	35, 36 280, 281, 282, 287, 288, 289, 290, 295, 300, 310, 321, 327

INDEX

- Globigerinella*
siphonifera36 281, 287, 290,
296, 298, 300, 310,
321, 339
- Globigerinita glutinata* 36 280, 281, 287,
288, 290, 300, 310,
321, 327
- humilus*36 287, 310
- uvula*36 280, 281, 287,
288, 290, 310, 321
- Globigerinoides*
conglobatus37 279, 280, 290,
295, 296, 300, 307,
310, 321, 334, 338
- ruber*37 280, 281, 287,
288, 289, 290, 296,
298, 300, 307, 310,
321, 339
- sacculifer fistulosus*314
- trilobus immaturus* ..37 292, 310
- trilobus sacculifer*37 298, 300, 301,
310, 339
- trilobus trilobus*37 280, 281, 284,
290, 292, 296, 298,
299, 300, 307, 310,
321, 332, 334, 339
- Globobulimina pacifica*246, 288
- Glbboquadrina altispira* ..321
- conglomerata*38 280, 284, 296,
298, 300, 301, 307,
310, 321, 334, 339
- venezuelana*321
- Globorotalia*
crassaformis38 284, 285, 288,
290, 295, 296, 299,
300, 304, 310, 321,
326, 327, 334, 338
- foshi foshi*284, 322
- hirsuta*39 281, 287, 288,
290, 296, 298, 300,
310
- inflata*39, 40 277, 280, 281,
285, 287, 290, 288,
295, 296, 297, 298,
299, 300, 302, 304,
310, 313, 321, 329,
334, 338, 339
- inflata zone*301, 302, 314,
317
- punctulata*295
- mayeri*40 284, 285, 291,
310, 312, 314, 322,
334, 337
- mayer zone*289, 292, 314
- menardi menardi*40 281, 292, 296,
298, 310, 339
- menardi tumida* .40, 41 279, 280, 284,
285, 292, 296, 298,
300, 306, 307, 310,
332, 334, 339
- scitula praescitula*321
- scitula scitula*41, 42 280, 286, 287,
288, 290, 300, 310,
321, 327
- tosaensis*305
- truncatulinoideis*42 277, 280, 281,
282, 284, 285, 287,
288, 306, 310, 314,
317, 322, 329, 331,
332
- Globorotaloides*
hexagonus42 280, 281, 287, 290
290, 292, 295, 298,
300, 310, 321, 334,
339
- glutinata*,
Globigerinita36 280, 281, 287,
288, 290, 300, 310,
321, 327,
- goudkoffi*, Bolivia273
- granti*, Bolivia273
- Guadalupe Arrugado*,
Mexico320
- Guaymas Basin, Gulf of*
California254, 255
- Gulf of California*239, 240, 248,
253, 256, 258, 274,
335
- characteristics of basins255
- Foraminifera of255
- planktonic Foraminifera303
- Pliocene of240
- trapped faunas in303
- Gyroidina altiformis*246
- gemma*247
- soldani*247
- ## H
- Hallian Stage*241, 267, 285,
288, 290, 310, 319
- Hanzawaia nitidula*246, 258, 263,
264, 274, 275, 307,
319
- hebespinata*, *Bulimina*
pagoda246, 256

INDEX

hexagonus,	
Globorotaloides	42 281, 287, 290, 292, 298, 300, 310, 321, 334, 339
hirsuta, Globorotalia ..	39 281, 287, 288, 290, 296, 298, 300, 310
hispidia, Uvigerina	247, 264
hispidocostata, Uvigerina..	239, 247, 256, 270
homeomorphic	
relationships	244
Honshu, Japan,	332, 340
planktonic Foraminifera	
of	334
hootsi, Bolivina	273
hootsi, Uvigerina	245, 247
hughesi, Bolivina	247, 254, 273
humilus, Globigerinita..	36 287, 310

I

incertum, Elphidium	245
inferred surface	
temperatures	315
inflata,	
Globorotalia	39, 40 277, 280, 281, 285, 287, 288, 290, 295, 296, 297, 298, 299, 300, 301, 302, 304, 306, 307, 310, 313, 317, 321, 329, 334, 336, 339
immaturus, Globigerinoides	
trilobus	37 290, 292, 310
inner shelf species	245, 287
interjuncta, Bolivina	235, 246, 288

J

Japan	284, 299, 305
Java	306
JOIDES	320
juncea, Uvigerina	246, 264, 288, 289

K

kernensis, Uvigerina	246
Kuroshio Current	279, 280, 284, 331, 341

L

lamarckian, Quinqueloba..	245
laminated diatomite	254, 256, 259,
Lasuen Bank, California ..	257
late Miocene, planktonic	
assemblages	291
late Pliocene, planktonic	
trends	303
surface temperatures	307
limbata, Cassidulina	246
lobatus, Cibicides	245
location of sections	
studied	221
Lomita Marl, California ..	308
lomitensis, Cassidulina	246
Los Angeles Basin,	
California	224, 225, 250, 252, 260, 265, 302, 318, 319, 335, 337
formations in	223
microfaunal stages	223
planktonic correlations	
in	317
Los Angeles County	
Museum of Natural	
History	218
low oxygen environments	245, 247, 254, 270, 273, 275
lower bathyal environment	219
lower middle bathyal	
species	246
lower Pliocene, planktonic	
biofacies	324, 332
planktonic indices	329
rates of sedimentation ..	325
subtropical, planktonic	
biofacies	322, 323, 341
Luisian Stage	284, 285, 320

M

major planktonic zones	310
Malaga Cove section,	
California,	221, 225, 228, 229, 234, 250, 254, 259, 295, 297, 302, 317, 318, 319, 323, 324, 336
benthic faunal groups ..	251
foraminiferal number	252
glauconite	252, 257
paleobathymetric trends:	252

INDEX

planktonic biofacies	296	Mission Hills section,	
potassium-argon date in	253	California	221, 229, 231,
sample locations	233		266, 270, 274, 275,
variation of surface			289, 292, 293, 317,
temperatures	315		336, 337
vitric tuffs	260	benthic faunal groups ..	272
Malaga Mudstone,		displaced species	271
California	227, 250, 254,	foraminiferal number ..	272
	256, 257, 259, 296,	laminated diatomite	270
	336	paleobathymetric trends	272
potassium-argon date in	296	radiolarian number	272
malkinae, Pullenia	246	Modelo Formation,	
marginal eastern		California	229, 266, 267,
North Pacific,	219, 278, 282,		272, 290, 330, 336
	313	potassium-argon date in	253, 266
oscillation of planktonic		modeloensis, Cassidulina..	246
biofacies	330	Mohnian Stage	229, 239, 240,
marginata, Bulimina			250, 254, 266, 267,
denudata	246, 288, 289		268, 270, 272, 283,
marginata, Bolivina			284, 285, 290, 291,
multicostata	246		292, 293, 295, 296,
mayeri, Globorotalia ..40	284, 285, 291,		301, 310, 319, 320,
	310, 314, 322, 334,		327, 340
	338	MOHOLE	234, 301, 320,
mckennai, Cibicides	246, 264		322, 323, 328, 341
Melonis barleeanus	246	planktonic Foraminifera	
Melonis pompilioides	235, 238, 247,	in	320, 321
	257, 263, 264	rates of sedimentation ..	325
menardi, Globorotalia ..40	281, 292, 296,	Monterey Shale,	
	298, 310, 339	California	227, 250, 283
mexicana, Bulimina striata	235	Montesano Formation,	
middle bathyal		Washington	234, 239, 325,
environment	219		326, 328, 330
species	254	planktonic Foraminifera	
middle Miocene, surface		in	327
temperatures	313	multicostata, Bolivina	
middle Pliocene, planktonic		marginata	246
trends	302		
surface temperatures	302, 303, 304,		
	316		
migration of isotherms	301		
migration of planktonic			
faunas	311		
minutissima, Globigerina..	321		
Miocene-Pliocene			
boundary	218, 219, 220,		
	224, 237, 240, 241		
	266, 273, 277, 278,		
	293, 294, 295, 299,		
	313, 314, 333, 336		
planktonic criteria	295		
minuta, Cassidulina	246		

N

Nassellaria	244
National Science	
Foundation	218, 220
nepenthes, Globigerina	312
New Zealand	305
Newport Mesa section,	
California,	221, 231, 236,
	240, 284, 285, 289,
	291, 292, 295, 297,
	302, 306
planktonic facies	285, 305
nitidula, Hanzawaia	246, 258, 263,
	264, 274, 275, 276,
	307, 319

INDEX

- Nonionella basispinata*, ... 235, 245, 288,
 289
 miocenica stella 235, 245, 288,
 289
 North America 301, 325
 North Pacific Ocean, 219, 303, 306,
 316, 325, 329, 338,
 340
 isotherm patterns 278
 planktonic Foraminifera 332
 rates of sedimentation 325
 surface circulation 279
 surface geostrophic
 circulation 278
 surface temperatures 279
- O**
- obliqua*, Bolivina 247, 266, 273
obliquiloculata,
 Pulleniatina 43 279, 280, 281,
 298, 300, 301, 310,
 332, 334, 338
 281, 286, 287,
 289, 290, 296, 298,
 300, 310, 321, 322
Orbulina suturalis 322
 oscillation of temperate
 planktonic biofacies 312
 outer shelf species 245
ovoidea, *Chilostomella* 246
Oyashio Current 280
 oxygen minimum zone 247
- P**
- pachyderma*,
 Globigerina 33, 34 272, 278, 280,
 281, 282, 284, 285,
 286, 287, 288, 289,
 292, 294, 296, 298,
 302, 304, 307, 309,
 321, 322, 326, 327,
 328, 329, 334, 338,
 339
 Pacific Beach section,
 California 221, 229, 231,
 306, 336, 338
 planktonic Foraminifera 304, 307
pacifica, Bolivina 246
pacifica, *Globobulimina* 246, 288
pacifica, *Trochammina* 245
pacifica-smithi,
 Epistominella 246
 paleobathymetric
 interpretation 241, 245
 paleo-California Current 219, 291
 Palos Verdes Hills,
 California 221, 227, 250,
 257, 258, 259, 319
 Palos Verdes uplift 257
 Panamanian Province 239, 284, 319,
 328
 parva, Bolivina 240, 273
 peregrina, *Uvigerina* 235, 246, 273,
 Pescadero Basin, Gulf of
 California 255
 Phillipines 290
 Phleger sampler 236
 Pico Formation,
 California 260, 264, 268,
 287
 potassium-argon date in 288
 planktonic-benthic ratio,
 definition 242
 planktonic Foraminifera,
 Balcom Canyon section 288
 boreal faunas 284
 Bunker Hill section 301
 Early Pliocene trends 297
 effect of asymmetric current
 system 278
 inferred surface temperature
 of 315
 inner shelf fauna 289
 late Miocene trends 289, 291
 late Pliocene trends 303
 latitudinal distribution.. . . . 332
 Honshu, Japan 334
 Malaga Cove section 296
 marginal eastern
 North Pacific 280
 Middle Pliocene trends
 zonation in southern
 California 289
 MOHOLE 321
 Montesano Formation 327
 Pacific Beach section 304
 paleo-oceanographic
 inferences 313
 Pleistocene trends 307
 Pliocene trends 339
 Quinault Formation 327
 Recent 231, 277
 Repetto Hills section 300
 San Diego Formation 304
 time-lag in appearance 394

INDEX

- summary of ranges 310
 - zonation in southern California 314
 - planktonic indices 240, 311, 317
 - planktonic scale, precision of 312, 339
 - Pleistocene-Recent boundary 309
 - Pliocene, surface temperatures 313
 - Pico Formation, California 229, 248, 305, 330
 - poeyanum, Elphidium translucens 245
 - polar refrigeration 294, 301, 316
 - pompilioides, Melonis 235, 238, 247, 257, 263, 264
 - potassium-argon dates 220, 253, 266, 288, 308, 310, 321, 336
 - praescitula, Globorotalia scitula 321
 - proboscidea, Uvigerina 235, 247
 - Prunopyle titan 43 244, 285, 290, 296, 297, 310, 314, 317, 339
 - stratigraphic range 244, 295
 - upper limit 317
 - pseudoplicata, Bolivina 246
 - pseudospissa, Bolivina 247, 254, 270
 - Pullenia bulloides 235, 247, 263, 264
 - malkinae 246
 - salisburyi 246
 - Pulleniatina obliquiloculata 43 279, 280, 281, 281, 298, 300, 301, 310, 332, 335, 339
 - punctulata, Globorotalia 295, 326, 327
- Q
- quadrilatera, Globigerina bulloides 33
 - quantitative faunal parameters 339
 - Quinqueloculina akneriana angulostriata 245
 - costata 245
 - lamarckiana 245
 - Quinault Formation, Washington 234, 326, 328, 330
 - planktonic Foraminifera quinqueloba, Globigerina 35, 36 280, 281, 282, 287, 288, 289, 290, 295, 300, 310, 321, 327
- R
- Radiolaria, 219, 227, 255, 268, 288
 - maximum diameter 256
 - Nassellaria 243
 - panbathypelagic 297
 - Spumellaria 243
 - radiolarian facies 240, 256, 293, 336
 - radiometric dates 243, 310
 - radiometric time scale 223, 224
 - rankini, Bolivina 283, 247, 273, 337
 - Repettian Stage 225, 240, 241, 253, 283, 285, 300, 301, 310, 327, 328 334
 - Repetto Formation, California 225, 227, 229, 234, 236, 250, 253, 256, 257, 260, 264, 267, 272, 290, 296, 300, 301, 323, 330
 - lithologic characteristics 260
 - vitric tuffs in 250
 - restricted basin faunas 247, 254
 - reworked species 249
 - Rincon Shale, California 283
 - rostrata, Bulimina 238, 247, 263
 - Rotorbinella garveyensis 238
 - ruber, Globigerinoides 37 280, 281, 288, 289, 290, 296, 298, 300, 307, 310, 321, 338
 - R. V. Velero 236
- S
- sacculifer, Globigerinoides trilobus 37 298, 301, 310, 314, 339
 - Sal si Puedes Masin, Gulf of California 255

INDEX

salisburyi, Pullenia	246	soldani, Gyroidina	247
sample locations,	227	South Pacific Ocean	301, 326, 331
Balcom Canyon section ..	232	"Sphaeroidinella	
Malaga Cove section	228, 229	dehiscens"	43 277, 280, 281,
Pacific Beach section ..	232, 233	284, 285, 290, 296,	
Recent sediments	234	297, 298, 299, 300,	
Repetto Hills section ..	226	301, 306, 310, 312,	
San Diego area	317	314, 317, 321, 322,	
San Diego-Capistrano area,		329, 332, 334, 338,	
California	223	340	
San Diego Formation,		Sphaeroidinellopsis	
California	229, 231, 233,	seminulina	43 292, 293, 299,
303, 306, 307, 336,		301, 321, 322, 334,	
338		338	
planktonic Foraminifera	304	"Sphaeroidinellopsis	
"San Diego horizon"	312	seminulina zone"	289, 293, 314
San Fernando Basin,		Sphaeroidinellopsis	
California	228, 266, 319	subdehiscens	43 292, 299, 310,
San Pedro Basin,		311, 312, 314, 335,	
California	265, 325	339	
San Pedro Martir Basin,		spissa, Bolivina	246, 264
Gulf of California	255	Spumellaria	243, 256, 259,
San Pedro Shelf,		271	
California	257	stella, Nonionella	
Santa Barbara area,		miocenica	245, 288, 289
California	292	Stilostomella adolphina ..	247
Santa Maria Basin,		advena	247
California	307	subacuminata, Bulimina ..	246, 256
Santa Monica Basin,		subcalva, Bulimina	246
California	265	subdehiscens,	
Santa Monica Mountains,		Sphaeroidinellopsis ..43	292, 299, 310,
California	221, 228, 266	314, 335, 339	
Saucesian Stage	239, 283	subfusiformis,	
scitula,		Buliminella	246, 264
Globigerinita	41, 42 280, 281, 286,	subperuviana,	
287, 288, 290, 300,		Epistominella	246
310, 321, 327		subquadrata, Cassidulina	
seamounts	219, 225, 302	subglobosa	246
324, 325		Suggrunda eckisi	245, 247
segundoensis, Uvigerina...	246	surface temperatures,	
seminuda, Bolivina	238, 247, 254,	late Miocene	294
270, 273		late Pliocene	304, 306, 307
seminulina		late Tertiary	315, 316, 340,
Sphaeroidinellopsis	43 292, 293, 299,	341	
301, 321, 322, 334,		298	
338		Lower Pliocene	298
senticosa, Uvigerina	235, 247	Middle Pliocene	303
sinuata, Bolivina	246, 254	Middle Miocene	313
Siphogenerina	239	migration of isotherms	328
siphonifera,		Pleistocene	309
Globigerinella	36 280, 281, 287,	Pliocene	313
290, 296, 298, 300,		Upper Miocene	298
310, 321, 338		suturalis, Orbulina	322

INDEX

T

Tanner Bank, California ..	258
Tarzana Submarine Fan, California	268, 270, 271, 275, 276, 293
Tecolote Tunnel, California	282, 283
tenerrima, <i>Buccella</i>	245
tepida, <i>Ammonia beccari</i> ..	245
Timms Point Silt, California	308
titan, <i>Prunopyle</i>	43 244, 296, 297, 310, 314, 338
tortuosa, <i>Cassidulina</i>	235, 246
torqueata, <i>Bolivina</i>	246
tosaensis, <i>Globorotalia</i>	305
translucens, <i>Cassidulina</i> ..	235, 246, 264
trilobus, <i>Globigerinoides</i> trilobus	37 280, 281, 284, 292, 296, 298, 299, 300, 307, 310, 321, 332, 334, 339
<i>Trochammina inflata</i>	245
<i>pacifica</i>	245
tropical-subtropical planktonic biofacies	330
truncatulinoides, <i>Globorotalia</i>	42 277, 280, 281, 282, 284, 285, 287, 288, 305, 306, 310, 312, 314, 317, 322, 329, 331, 332, 335, 340
tumida, <i>Globorotalia</i> <i>menardi</i>	40, 41 279, 280, 284, 285, 296, 300, 306, 307, 310, 332, 335, 339
turbidites	240, 248, 249, 260, 268, 271, 337

U

upper bathyal species	246
upper middle bathyal species	246
upper Pliocene, planktonic trends	303
surface temperatures	304, 305, 306
<i>Uvigerina hispida</i>	247, 264
<i>hispidocostata</i>	239, 247, 256, 270

hooysi	245, 247
juncea	246, 264, 288,
kernensis	246
peregrina	235, 246, 273, 288
<i>proboscidea</i>	235, 247
<i>segundoensis</i>	246
<i>senticosa</i>	235, 247
<i>uvigerinaformis</i> , <i>Bulimina</i>	240
uvula, <i>Globigerinita</i> ..	36 230, 281, 287, 288, 290, 310, 321, 328

V

Valmonte Diatomite, California	227, 250, 253, 254, 256, 259, 296, 336
valmonteensis, <i>Discorbinella</i>	246, 270
Valvulineria <i>araucana</i> .	247, 254, 270
Vaqueros Sandstone, California	283
vaughani, <i>Bolivina</i>	245
venezuelana, <i>Globoquadrina</i>	321
Ventura area, California ..	223, 266
Ventura Basin, California	224, 225, 231, 335
formations in	223
microfaunal stages	223
Ventura Embayment, California	319, 336, 340
Venturian Stage ..	240, 267, 285, 290, 310
Virgulina <i>californiensis</i> ..	240

W

Washington ..	238, 282, 325, 327
western North Pacific	278, 279, 305
Wheelerian Stage	240, 241, 267, 272, 285, 288, 290, 310, 319

Z

Zemorrian Stage	283
zoogeographic provinces ..	244



TABLE 10. RELATIVE ABUNDANCE OF FORAMINIFERA IN THE REPETTO FORMATION, REPETTO HILLS SECTION

TABLE 3 - RELATIVE ABUNDANCE OF FORAMINIFERA AND RADIOLARIA IN THE REPETTO FORMATION, MALAGA MOUNTAIN, AND VALMONTÉ DATUMATE.

TABLE 11
RELATIVE ABUNDANCE OF FORAMINIFERA AND RADIOLARIA IN THE MODELO AND NEPETTO FORMATIONS, WOODLAND HILLS SECTION

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